For Note on Index, see:
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EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

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Editorial.

A Simple Method of Measuring Modulation.

EVERY experimenter will welcome a method of determining the degree of modulation of the received waves, especially if the method calls for no very elaborate equipment. Such a method is described in an article by Mr. L. B. Turner in this number. The method has its limitations in that it measures the average value and not the momentary peaks which so often cause trouble, but a knowledge of the average modulation over an interval of a few seconds is of great interest in determining the relation between the modulation ratio and the quality of the reproduction. The time over which the average is taken depends on the sluggishness of the indicating instrument employed with the valve voltmeter. We have no doubt that many of our readers will try this method, and we shall welcome any interesting particulars of their observations, and especially of any modifications or improvements introduced into the method.

We are not in entire agreement with Mr. Turner's formula for the modulator ratio; in our opinion a simpler denominator gives a more accurate value. Our reasons for this opinion will be evident from the following considerations, assuming that one has already read Mr. Turner's article. It is found that the carrier wave alone causes the anode current to change from i to $i—\delta i$; it is then found that with the aerial cut out, the same change of anode current can be produced by inserting a resistance r in the anode circuit, and thus increasing its total external resistance from r_0 to r_0+r. Under these circumstances the change in the anode voltage of the valve is $ri—(r_0+r)\ \delta i$ and, as Mr. Turner says, the change δi could have been produced by a change of anode voltage of this magnitude. He then says "or by a grid change $1/\mu$ times as great"; but this is not correct, because, owing to the external resistance r_0 in the anode circuit, the anode voltage is not constant, but changes with every change in i. To make the effect of this clear let us assume that the anode current is given by the equation $i=av_a+bv_g+c$ where a, b and c are constants and v_a and v_g are the anode and grid voltages; let E be the E.M.F. of the anode battery and r_0 the external resistance of the anode circuit, then

$$a\,[E-ir_0]+bv_g+c=i.$$

Now let v_g become $v_g-\delta v_g$; i will decrease to $i-\delta i$ then

$$a\,[E-(i-\delta i)\,r_0]+b(v_g-\delta v_g)+c=i-\delta i.$$

(*Note.*—We are following the author's unusual procedure in assuming that δi is essentially positive and writing $i-\delta i$ instead of $i+\delta i$ for the new value of current.)

In the other case the grid voltage is unchanged—the aerial being cut out—but the anode circuit external resistance is increased from r_0 to r_0+r, also causing i to decrease to $i-\delta i$; we then have

$$a\,[E-(i-\delta i)(r_0+r)]+bv_g+c=i-\delta i.$$

From the 1st and 2nd equations we have

$$-a\delta i r_0 + b\delta v_g = \delta i$$

and from the 1st and 3rd equations we have

$$a[ir - \delta i(r_0 + r)] = \delta i.$$

Equating these two values of δi we have

$$b\delta v_g = a[ir - \delta i(r_0 + r)] + a\delta i r_0$$

which, since $b/a = \mu$, may be written

$$\delta v_g = \frac{r(i - \delta i)}{\mu}$$

The expression for the modulation ratio will then be $\dfrac{\sqrt{2}\, e}{r(i-\delta i)}$ instead of $\dfrac{\sqrt{2}\, e}{ri - (r_0 + r)\delta i}$

There is thus no need to know r_0.

The effect on the values of the modulation ratio is seen from the following table:—

Observation.	Modulation Ratio.	
	Turner.	Howe.
1	per cent. 15	per cent. 14
2	35	35
3	28	28
4	61	58
5	42	40
6	33	33
7	48	47
8	55	50
9	18	17

It will be seen that the values are lower than those given by Mr. Turner, but the difference is so small, in view of the very approximate nature of the measurements, that the additional accuracy would be hardly worth while were it not that the more accurate formula is the simpler of the two and requires the measurement of one less quantity.

Classification of Articles and Abstracts.

In our issue of October, 1924, a very instructive description was given of the Dewey Decimal System of Classification and the extension of it introduced by the Bureau of Standards. To make it more suitable for Radio Telegraphy some further modifications were introduced by Mr. P. K. Turner and since that time a number—we almost said a cryptic number—has appeared beside the title of every article. This number enabled the initiated to place the article in its correct niche in the Dewey Decimal System without reading it.

Since the arrangement was entered into whereby the abstracts prepared by the Radio Research Board of the Department of Scientific and Industrial Research are published in *E.W. & W.E.*, these abstracts have been split up into groups according to their Dewey classification, but this has not proved very satisfactory and after due consideration an improved method of grouping has been agreed upon and adopted in the present issue. Unlike a general library, we are not concerned with many branches of learning, but with one subject which can be conveniently grouped into a relatively small number of sections. We would point out, however, that any reader who uses the Dewey System, and is consequently familiar with the classification, can still apply it by reading through the abstract—a glance would often suffice—and noting the relevant number.

The headings under which the abstracts will be grouped are as follows:—

Propagation of Waves.
Direction Finding.
Atmospherics.
Properties of Circuits.
Valve Design and Thermionics.
Transmission.
Reception.
Measurements and Standards.
Subsidiary Equipment and Materials.
Stations; Design and Operation.
Miscellaneous.

Telephone Transmitter Modulation Measured at the Receiving Station.

By L. B. Turner, M.A., M.I.E.E.

1. Introduction.

THE envelope of the shaded area in Fig. 1 represents the amplitude of high frequency current in the aerial of a wireless telephone transmitter when an acoustic tone of frequency n is being transmitted. The high frequency amplitude is a when the microphone is quiet, and fluctuates between $(a+\alpha)$ and $(a-\alpha)$ when the tone is played or sung to the microphone.

The ratio α/a, called the modulation ratio, has great significance for the quality of reproduction by the receiver. However perfect the amplifiers and loud-speaker may be, they reproduce the harmonics of the transmitted tone which are manufactured in the rectifier. The strengths of these undesired harmonics relative to the strength of the desired fundamental decrease as the modulation ratio α/a is decreased. This is the ground for the term "over-modulation" as a fault at the transmitter. Over-modulation shows, of course, only during the relatively loud passages.

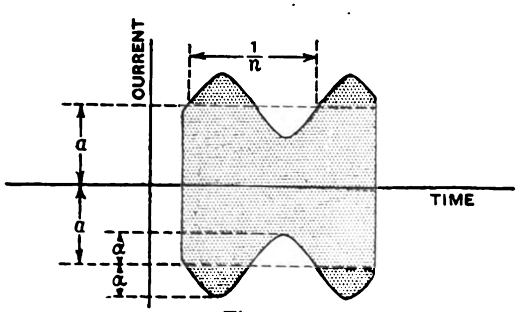


Fig. 1.

While the power capacity of the transmitting plant limits a, the strength of the received signal is proportional to α. In the effort to provide good *strength* of signals, those in control of the transmitter are therefore tempted to make α larger than is consistent with good *quality*.

Doubtless every critical broadcast listener sometimes judges that his favourite transmitting station (Daventry, in the writer's case) is producing music of a quality distinctly below par—showing faults, that is, not attributable to the musical score or to the performers, but of the sort which would suggest misbehaviour of the receiver had not that erstwhile suspicionable new acquaintance developed gradually into a trustworthy friend. The writer has several times noticed —or fancied so—that on such occasions the strength of the signals was abnormally great. It seems probable that an abnormally high modulation ratio is responsible for such occurrences.

The writer does not know of any published statement of modulation ratios used in the British Broadcasting Company's stations. It has been stated, however, that in 1922-23 the modulation at KDKA, the Westinghouse Co.'s station at East Pittsburgh, reached from 50 per cent. to 90 per cent.*; and that at the Telefunken Co.'s stations in Germany "it has been found desirable to modulate only 55 per cent. for speech at the transmitter and only 35 per cent. for music."†

Experimentalists and others interested in the big question of quality of reproduction are vitally concerned with the transmitter's modulation ratio, and it is important for them to be able to determine it themselves. A simple method is here described. It requires very little apparatus not already incorporated in the ordinary triode receiver for use with headphones. The chief accessory is a triode voltmeter; but this is an instrument for measurements of all sorts which no wireless experimenter can afford to be without.

2. Apparatus and Procedure.

Fig. 2 is a complete circuit diagram.

RT is the normal rectifier triode, which may be for grid rectification as shown, or for anode rectification.

* C. M. Jansky, *Technological Papers of the Bureau of Standards*, No. 297, Oct., 1925.

† W. Schäffer, *Telefunken Zeitung*, No. 42, Jan., 1926, p. 22.

B2

B is its anode battery.

Ch is an acoustic frequency choke, whose reactance is large compared with the A.C. resistance of RT. It may be the primary of a good triode transformer.

R is an adjustable resistance, such as an ordinary plug box, of value r.

H is a headphone of low resistance, or with a shunt of low resistance, for observing the music during the tests.

mA is a milliammeter, measuring the anode current i.

μA is a microammeter or galvanometer or low-reading milliammeter, indicating (and roughly measuring) small changes of i.

TV is a thermionic voltmeter, of a type unaffected by steady P.D. between its terminals. It reads the R.M.S. acoustic P.D. e across Ch.

P is a potential divider, supplemented by cells C if necessary.

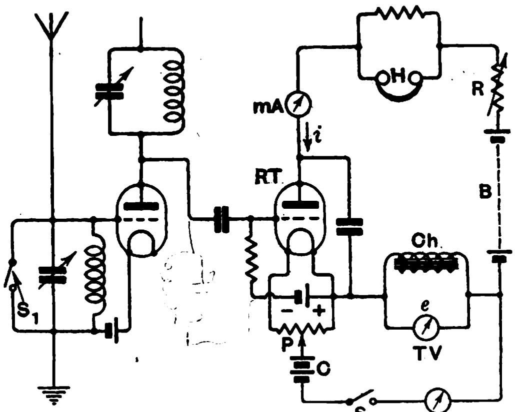


Fig. 2.

S_1 is a switch, cutting off the signals when closed.

S_2 is a switch, removing μA when open.

The receiver being tuned to the station under observation,* the procedure is as follows :—

I. Close S_1 and S_2; set R to zero; and adjust P to bring μA to a convenient part of its scale.

II. During an interval in the programme when the microphone is quiescent,† open S_1 and observe the consequent change on μA. This is a measure of the change of anode current effected by the signal; call it δi.

III. Close S_1, and adjust R (to a value r) to produce the same movement on μA as was produced by the signal in II.

IV. Open S_1 and S_2; listen in H, and at a selected passage in the music observe the voltmeter reading e. This is the P.D. produced by the modulation.

The required modulation ratio is given approximately by the simple formula $\sqrt{2}\,e/ri$. A correction is necessary, however, for accurate results unless δi is very small compared with i. It will be observed that the triode dimensions need not be known.

* This is best checked in operation II.

† This may actually be done when the microphone is quiescent or not; quiescence makes no difference but it simplifies the argument to establish the formula.

3. Derivation of the Formula.

Let μ, ρ be the amplification constant and the A.C. anode resistance of the triode. Let r_0 be the external resistance of the anode circuit—viz., that of the choke Ch shunted by the microammeter μA, plus that of the headphone H shunted by the small resistance.

The additional anode circuit drop effected in III is $ri-(r+r_0)\delta i$, which is approximately ri if δi is sufficiently small. Hence δi in II would have been produced by an anode change $ri-(r+r_0)\delta i$, or a grid change $1/\mu$ times as great.*

The anode acoustic amplitude $\sqrt{2}\,e$ in IV (when the signal is substantially a single tone) gives $\sqrt{2}\,e/\mu$ as the grid acoustic amplitude, since the impedance of Ch is much greater than ρ.

Hence the modulation ratio is

$$\frac{\sqrt{2}\,e}{\mu} \div \frac{ri-(r+r_0)\delta i}{\mu}$$

$$= \frac{\sqrt{2}\,e}{ri-(r+r_0)\delta i}$$

Strictly the modulation ratio thus found is the ratio between the amplitude of the acoustic part of the rectified current and the steady part of the rectified current due to the carrier wave. It is this ratio which matters as regards quality of reproduction; but it is equal to the transmitter modulation ratio only if rectified current is sensibly propor-

* In the grid rectifier case, this is the drop of grid potential actually effected by the carrier wave.

tional to high frequency amplitude. The good quality of musical reproduction usually obtainable, in the presence of high modulation ratios such as those recorded below, shows that this must be the case; and direct laboratory measurements have confirmed it.

4. Examples of Measurement.

The transmitter was Daventry ($\lambda=1{,}600$ m). The receiver was as in Fig. 2; the situation, Cambridge; the aerial, a poor one between low chimneys. Ch was the primary of a 1 : 2 transformer of good make; its resistance was 1,200 ohms. The headphone H was of high resistance, and was shunted by resistance varying between 0 and 500 ohms. The microammeter was an instrument with variable shunt, the resistance as used having values between 900 and 180 ohms. B gave about 105V. The amplification of the first triode was intentionally varied during the series of tests, by changes of triode and of its anode voltage.

Each observation was made at a relatively rather loud passage in the particular musical item.

With signals adequate for good headphone strength at the anode of a triode rectifier these measurements are made without difficulty. The procedure may obviously be varied in detail; and a correction may be applied if the impedance of the choke Ch is not indefinitely great compared with the anode A.C. resistance ρ. It is a help in arranging that the impedance of Ch is sufficiently large, especially when anode rectification is employed, to use for RT a triode with low A.C. anode resistance—*e.g.*, the triode which normally feeds the loud-speaker. Such a triode permits, too, a wider sweep of grid voltage without endangering the rectilinearity of rectifier response.

It is necessary to guard against high frequency P.D. reaching Ch and giving a reading on TV. If Ch is the primary of a transformer of known ratio, it is convenient to place TV across the secondary.

The writer has used the method only with grid rectification, the grid-leak being 1.5 megohms; but it does not appear that the substitution of anode rectification would raise any serious difficulty.

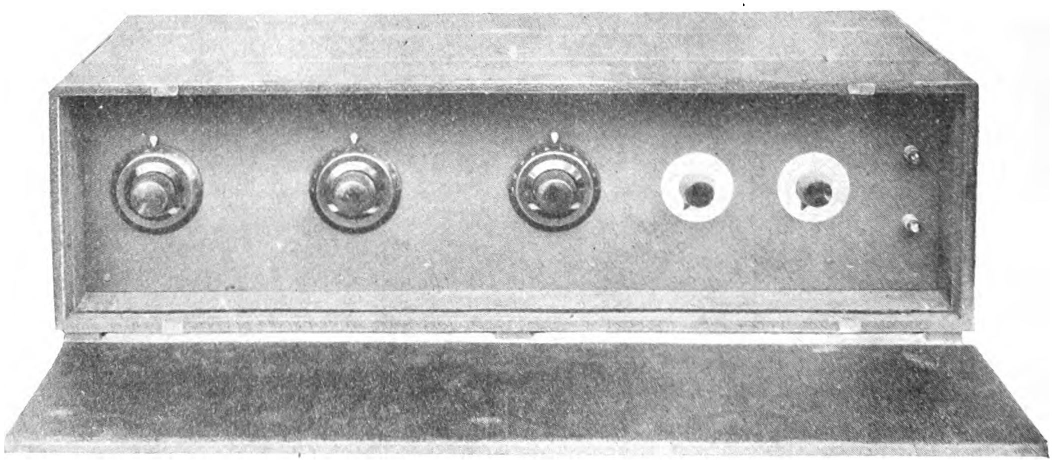
Observation.	Triode.	i (mA)	δi (mA)	r_0 (ohms)	r (ohms)	Musical item.	e (volts)	Modulation ratio.
1	Dull emr. (0.06A) Nominal $\mu=10$ $\rho=25$ kΩ	3.4	1.4	1,200	12,000	Contralto	2.4	15%
2	Do.	3.4	0.31	500	2,240	Cello	1.7	35%
3	Do.	3.4	0.31	500	2,240	Quartet	1.35	28%
4	G.E. Co.'s "D.E.4" Nominal $\mu=7$ $\rho=10$ kΩ	7.7	0.21	500	260	Tenor	0.8	61%
5	Do.	7.7	0.21	500	260	Quartet	0.55	42%
6	Do.	7.1	0.22	830	600	Big Ben, just after stroke	0.95	33%
7	Do.	7.7	0.69	180	920	Tuning note 7 p.m., on 26 Aug., '26	2.15	48%
8	Do.	7.0	0.40	830	560	Do., on 28 Aug., '26	1.3	55%
9	Do.	7.0	1.32	680	2,400	Orchestra	1.6	18%

Notes.—Observations 3, 5 and 9: Not a single tone.
Observation 7: High frequency P.D. on grid=0.95 V (R.M.S.).
Observation 8: High frequency P.D. on grid=ca. 0.6 V (R.M.S.).

A Five-Valve Receiver with Two H.F. Stages for 900-3,000 Metres.

By W. James.

THE five-valve receiver illustrated here was designed to receive Daventry and five or six of the European broadcast stations working between 900 and 3,000 metres. It might be thought that five is an extravagant number of valves to use for the purpose, as many of us can receive several of the long-wave stations with a two-valve set fitted with reaction. But five valves were used to make certain of receiving the stations even on a short indoor aerial, and good quality was considered essential. It was also thought that people living even thousands of miles away from, say, Daventry, would have a good chance of hearing this station under favourable conditions.



The completed receiver. The three condensers tune the aerial coil and high-frequency transformers. Two filament rheostats are used, the left-hand one being a volume control.

With five valves three tuned circuits can be used, thus giving good tuning ; adjustable reaction can be dispensed with, and the three tuned circuits, with the two valves which form the high frequency amplifier, can be made perfectly stable, as there is no need to design them to give the utmost amplification. Such a high frequency amplifier can be calibrated, if necessary ; in any case to tune it is easy as the individual stages are relatively broadly tuned and are free from interaction. Transformer coupling is used throughout, the two high-frequency transformers being home made and tuned by variable condensers, whilst the two low-frequency stages are coupled by good commercial instruments.

Referring to the circuit diagram of Fig. 1, L_1, C_1 ; T_1, C_2 and T_2, C_3 are the high-frequency couplings, T_3 and T_4 being the low-frequency couplings.

High-Frequency Couplings.

If we take a valve having an amplification factor (μ) of 6 and an A.C. resistance (R_{AC}) of 6,000 ohms, under working conditions, and we connect a tuned circuit to its anode, the maximum amplification obtainable is 6 and selectivity will be poor because of valve damping. To obtain practically the full amplification is easy, for we have only to provide a circuit having an effective resistance at resonance of, say, 10 times the A.C. resistance of the valve, or 60,000 ohms. It

is clear that we could do better by employing a valve with a higher amplification factor and a correspondingly higher A.C. resistance. For instance, if the valve is changed for one having a μ of 20 and an R_{AC} of 20,000 ohms, the tuned circuit remaining as before, the amplification obtained will be 15 and the selectivity will be better because now the tuned circuit is damped by a shunting resistance of 20,000 ohms instead of 6,000 ohms. Another advantage is that the 20,000 ohms valve does not take such a large anode current as the 6,000 ohms valve.

We will, therefore, use a high impedance valve; a good one is the Mullard PM5A, the average μ and R_{AC} at 120 anode volts and —1.5 volts grid bias for six which were tested being 25 and 30,000 ohms.

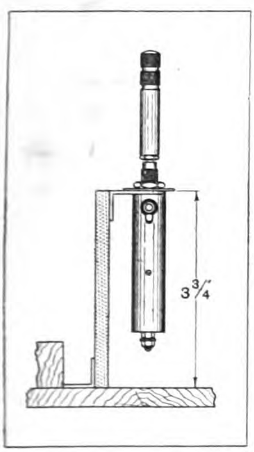


Fig. 2. *Method of mounting the Gambrell balancing condenser. The upright piece is of ebonite.*

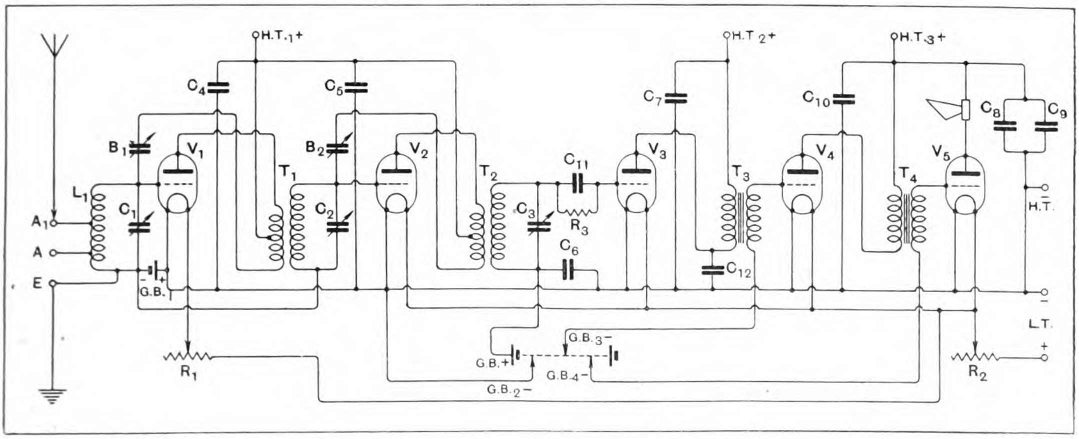


Fig. 1. *Circuit diagram.* C_1, C_2, C_3, 0.0005μF; C_4, C_5, C_6, C_7, 1μF; C_8, C_9, C_{10}, 2μF; C_{11}, 0.00025μF; C_{12}, 0.001μF; B_1, B_2, *Gambrell balancing condensers*; L_1, *Lewcos coil No.* 300; T_1, T_2, *H.F. transformers with balancing windings*; T_3, T_4, *L.F. transformers with good characteristics*; R_1, *volume control of approximately* 30 *ohms*; R_2, *filament rheostat*; R_3, 1 *megohm grid-leak*; V_1, V_2, *valves of high* μ *and about* 30,000 *ohms* R_{AC}; V_3, V_4, *detector and L.F. valves which should be chosen with regard to the quality required*; V_5, *output valve of about* 3,000 *ohms*; GB_1, *single dry cell*; $GB+$ *to* GB_4—, *grid bias of about* 27 *volts.*

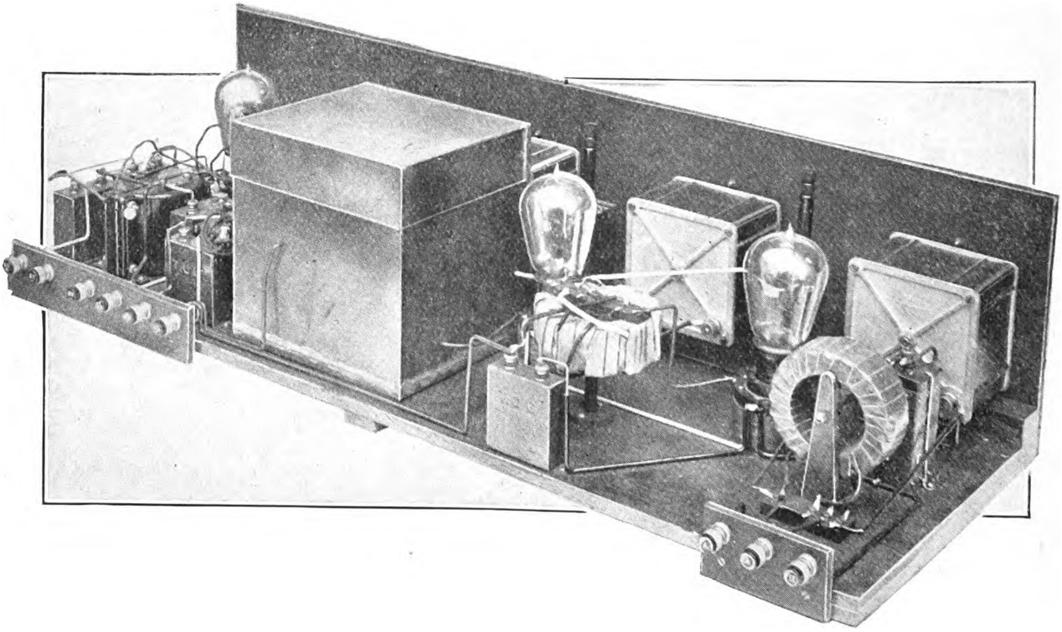
But it is possible to increase the amplification and to improve the selectivity by further adapting the tuned circuit to the valve. It should be remembered that the maximum *power* is delivered to a circuit when the effective resistance of the circuit is equal to the R_{AC} of the valve. The maximum is not very sharply defined, however, and it is possible to vary the ratio of the resistances to, say, 3 to 1 or $\frac{1}{3}$ without losing very much. This is an important point, as we require selectivity and stability as well as amplification.

Now it is an easy matter to provide a tuned circuit having an effective resistance of, say, 200,000 ohms at resonance, although from the discussion we see that there is not much use for it as it stands. But we can connect the anode of the valve to a portion of the tuned circuit, or what is really the same thing, we can use the tuned circuit as the secondary of a transformer and fit a primary to it. If, now, the circuit connected to the anode has an effective resistance approximately equal to the R_{AC} of the valve, the valve is being used efficiently and the voltage across the tuned secondary will be larger than that across the primary winding because of transformer action. It should be noted that under these conditions the voltage across the anode

circuit is divided approximately equally between the valve and its anode circuit, and that the best turns ratio of secondary and primary is about 2.6, giving an amplification of 32.5. Selectivity is correspondingly better owing to the reduction of valve damping. Under these conditions, that is with a transformer designed to match the valve and tuned to resonance, the amplification is a maximum.

having a secondary tuned by condenser C_2 and two primary windings; one primary is connected to the anode of V_1 and to +H.T., while the other is connected to +H.T. and through the balancing condenser B_1 to the grid of V_1.

It is important to wind the two primary windings close together, for then the coupling will be tight and the balance will hold over the whole tuning range of the transformer.



View of the back of the receiver, showing in particular the method of mounting the aerial coil (on the right) and the first H.F. transformer (between the two valves). The third tuned coupling and the detector valve is enclosed in the copper box. In front of the aerial coil are the aerial and earth terminals; the battery terminals are on the left-hand side.

Obtaining Stability.

If such a valve and transformer combination had a tuned grid circuit, the arrangement would undoubtedly oscillate violently even though the input and output circuits were completely screened. Valve capacity is the cause of the trouble and it is necessary to balance the anode-grid capacity.

There are several ways of doing this, but the one found most satisfactory consists of a winding tightly coupled to the primary of the transformer and connected to +H.T. and through a condenser of small capacity to the grid as in Fig. 1. Here valve V_1 is shown coupled to V_2 by transformer T_1,

It is very difficult, however, to remove all couplings between the input and output circuits and there may be a tendency for the valve to oscillate. For this reason it is better to provide the transformer with a smaller primary, making its effective resistance when the transformer is tuned, say, $\frac{1}{3}$ of the R_{AC} of the valve. The amplification will then be about 27.5 against 32.5, but selectivity is better and it will be very easy to stabilise the amplifier.

H.F. Transformers.

The coil L_1 and the secondary windings of transformers T_1 and T_2 are Lewcos No. 300

plug-in coils. These have an inductance of 4,800μH and a tuning range of 900 to 3,000 metres when shunted by a 0.0005μF variable condenser. At 2,320 metres the H.F. resistance of a Lewcos No. 300 coil is 28.2 ohms.

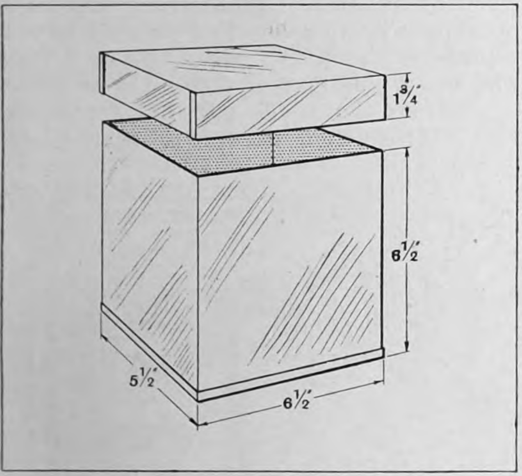


Fig. 3. *Details of the copper box which is of No. 24 gauge.*

Coil L_1 is tapped at the end of the first and second layers for the aerial connections A and A_1, the beginning of the first layer (the inside one) being connected to the earth terminal E. As the coils are wound with enamel insulated Litzendraht cable, it is necessary to bare the wires very carefully, to solder on flexible wires, and to bind them in position with tape. The coil is mounted in an upright position and is provided with a connection strip consisting of a piece of ebonite with screws and soldering tags bolted in position as shown in the right-hand drawing of Fig. 5. This coil is the one seen at the left-hand end when looking over the front of the set. The coil plug is not used.

H.F. transformers T_1 and T_2 are wound in the same way, T_1 being mounted at right angles to the aerial coil, while T_2 and the detector valve is enclosed in a copper box. From the coil data the best ratio for the transformer T_1 when using the optimum coupling and allowing a load of 1.0 megohm across the condenser terminals, is 5.5 : 1, giving an amplification of about 34. Actually the two primary windings have 60 turns each of No. 40 D.S.C. wire.

Before winding the primaries, the coil plugs and outer coverings are removed; three or four layers of Empire cloth are then wrapped over the outer surface of the coil and over this 120 turns of No. 40 D.S.C. copper wire are wound to cover the whole surface except for about one-tenth of an inch at each edge. To the beginning of the winding a flexible wire is soldered and tied to the secondary coil with cotton; this end is the one which connects to the anode of the valve. At the 60th turn a second flexible wire is soldered and tied down; this has to be connected to +H.T. The end of the fine wire winding, at turn 120, is similarly finished off; this wire has to go to one side of a

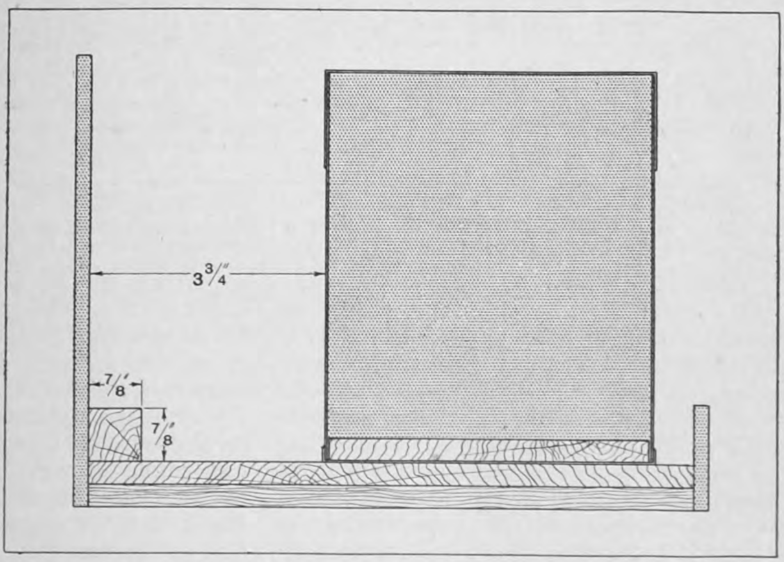


Fig. 4. *Position of copper box in the set. The parts enclosed in the box are mounted on the piece of wood. This drawing also shows the position of the baseboard, the end batten, the terminal strip, and the method of fixing the panel to the baseboard.*

balancing condenser. The primary windings (comprising the two coils) are wound in the same direction as the secondary, and the end of the secondary from the outside layer is the end that is connected to the grid bias. The primary windings are, therefore, wound over the portion of the secondary most nearly at earth potential.

Fine wire is used for the windings to keep down their size and to reduce their capacity to the secondary. Selectivity is adversely affected by the capacity of primary to secondary and so is amplification and it is important to reduce this capacity to as small a value as possible. This should not be done by increasing the distance between the two windings, for a weaker magnetic coupling has the effect of reducing the amplification at all points and certainly has the effect, in the transformers described, of making the amplification fall off seriously at the longer wavelengths. A weak magnetic coupling will improve selectivity, if only because valve damping is reduced.

The H.F. Amplifier.

The connections of Fig. 1 show that the grids of the H.F. valves, V_1 and V_2, are biased negatively by the battery GB_1; a single dry cell is used here.

A positive bias or a negative one can be given to the grid of the detector valve V_3 by appropriately connecting the grid return wire from the tuned circuit T_2 C_3. This wire has a plug marked $GB+$ and with the connections shown the grid has a positive bias. If the voltage between the connections $GB+$ and GB_2 is 6, the rectifier works exactly as it would if the grid return wire were connected directly to +L.T.; but the sensitivity of a grid circuit rectifier can often be improved by using a smaller voltage, such as 3 volts. However, from the point of view of quality it is generally preferable to connect the grid return wire to +6 volts and for the same reason a grid condenser C_{11} of 0.00025μF and a grid-leak of 1 megohm is used. The sensitivity of the detector to weak signals is improved by using a higher value

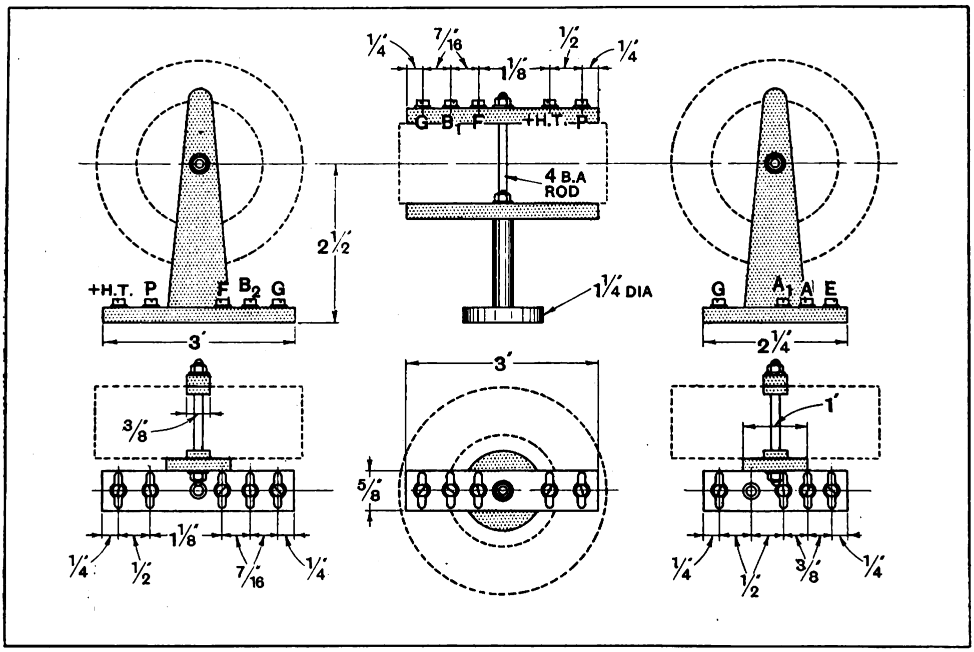


Fig. 5. Details of the aerial coil (right); and the two H.F. transformers. The transformers consist of a Lewcos No. 300 plug-in type coil with primary and balancing windings. Connection strips are bolted in position and to the supports.

of grid-leak and a little larger condenser, but at the expense of quality. Condenser C_6 shunts the grid bias of the rectifier.

Anode rectification can be obtained merely by connecting the grid return wire (marked $GB+$) to a point negative with respect to the filament, say 3 volts, and by adjusting the anode voltage at HT_2+.

The amount of the high frequency amplification obtained can be controlled in two ways: by varying the anode voltage at $H.T._1+$ or by varying the filament current of one or both H.F. valves. In each case, amplification is varied by altering the A.C. resistance of the H.F. valves; obviously, if the R_{AC} of the valves is increased the amplification is reduced and, incidentally, the selectivity is improved.

In the circuit diagram the rheostat R_1 is shown connected to V_1. If this has a value of 30 ohms for a valve taking a current of about 0.25 ampere, or 50 ohms for a 0.1 ampere valve, a smooth control of volume is obtained. If the volume control so obtained is inadequate in any particular case, a 30 ohms rheostat can be connected to the two valves V_1 and V_2, so that both valves are controlled. This method seems much to be preferred to the alternative one of varying the anode voltage although the anode voltage would naturally be set at a value found most convenient.

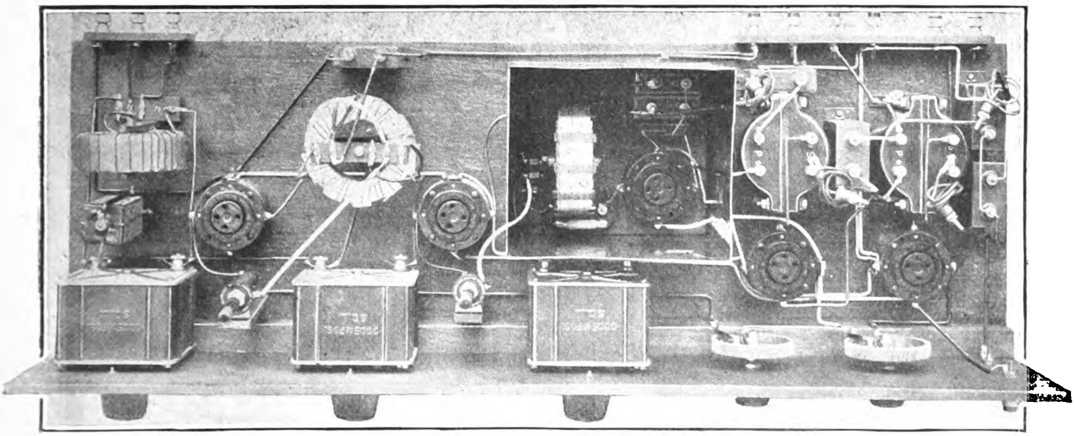
The L.F. Amplifier.

We can design the L.F. amplifier to give excellent quality regardless of the amplification obtained, or for maximum amplification. A person living a considerable distance from the stations he wishes to receive would naturally be more interested in getting the highest amplification with tolerable quality, as the signals received would probably be distorted to some extent in any case.

The quality of the amplification is determined by the valves and the couplings. If a valve having an R_{AC} of, say, 25,000 ohms is used as a detector and a good low ratio transformer with a primary inductance of 50 henries or more is used, the quality should be quite good; and if the valve has an amplification factor of 20 the amplification is considerable.

It is advisable to use a low ratio transformer because of the effect of the anode by-pass condenser C_{12} of 0.001μF and if the best quality is desired a valve having an R_{AC} of, say, 6,000 to 10,000 ohms should be used as the detector.

To couple the fourth valve to the output valve a transformer having a primary inductance of similar value to T_3 may be used with a valve V_4 of 6,000 to 10,000 ohms suitably biased. Such a combination will usually give excellent quality when the output



Plan view of the set with the cover removed from the copper box. Between the first and second tuning condensers is the balancing condenser (B_1), and between the second and third the other balancing condenser. The grid bias cell for the H.F. valves lies between the first tuning condenser and the aerial coil.

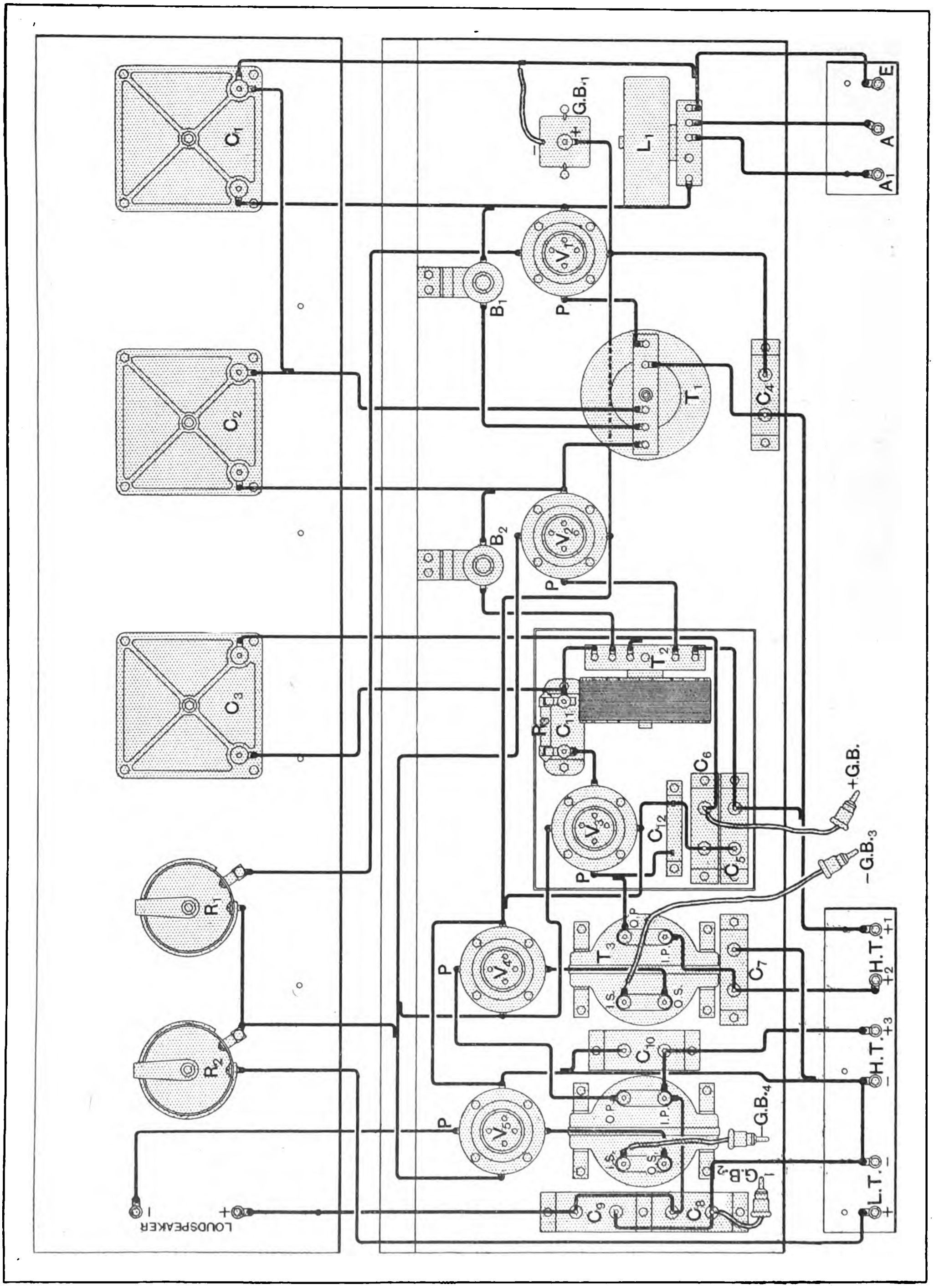


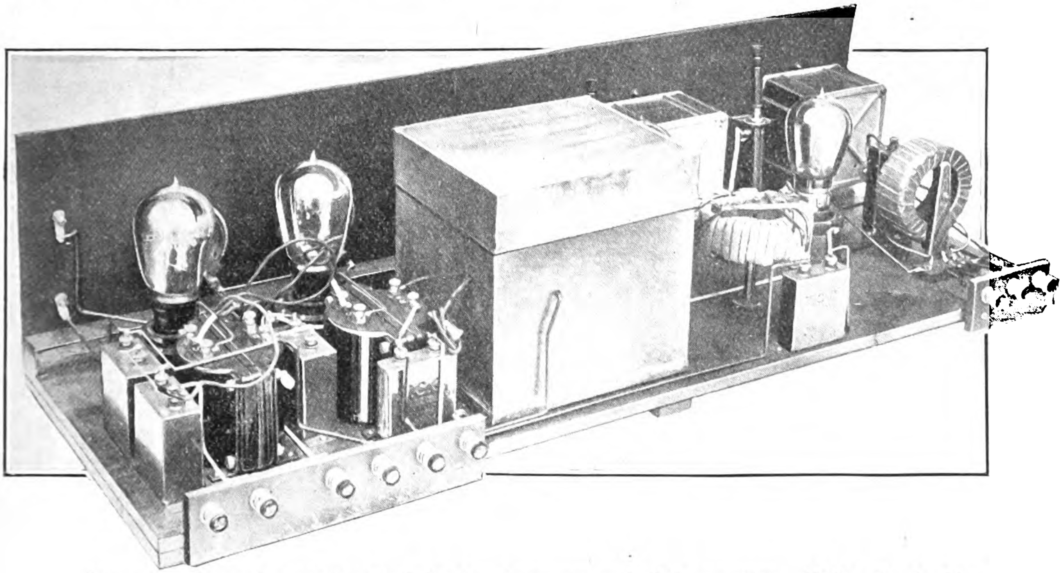
Fig. 7. *Wiring diagram. The drawing is to scale.*

valve V_5 is of the type having an R_{AC} of about 3,000 ohms. There are two important points which should not be lost sight of however: the first is whether the loud-speaker is a faithful reproducer, and the second whether the anode battery will economically supply the current required. If the loud-speaker to be used will not reproduce the very low tones it is obviously not necessary to make the set amplify them fully as currents of the lower frequencies add to the filtering difficulties.

a wide range of frequencies more or less equally well and it can only do this when the primary is of adequate size. Resonance, of course, plays a part at the lower and higher frequencies, but experience shows that a transformer having a large primary inductance is necessary if the lower notes are to be faithfully amplified.

Operation.

The illustrations and drawings show the construction and wiring of the receiver and



This view shows in greater detail the low-frequency end of the receiver. Notice the position of the two L.F. transformers, the two L.F. valves and the battery condensers.

With regard to the second point, it has to be remembered that the last valve requires a steady anode current of 12 milliamperes or so if it is to deal with strong signals satisfactorily and that the remainder of the set can be designed to take a total current of between, say, 5 and 15 milliamperes. When a dry battery is used as the source of anode current it is usually necessary to keep the total current as small as possible. This can be done by using high impedance (low ratio) transformers at T_3 and T_4 and valves having an R_{AC} of, say, 25,000 ohms at V_3 and V_4.

It should be noted that the remarks concerning H.F. transformers do not apply to low frequency transformers. A low frequency transformer is required to amplify

it is not necessary to enter into details. An ebonite panel 30 in. by $7\frac{1}{2}$ in. by $\frac{1}{4}$ in. is used, with a baseboard 30 in. by 10 in. by $\frac{1}{2}$ in. The components enclosed in the copper box are mounted on a base of wood and several of the wires can be put on before the base, with its components, is lowered in the box. Holes have to be drilled in the box to take the insulated connecting wires which pass from the inside of the box to apparatus outside.

The set is quite an easy one to build and operate. It should be remembered that the two H.F. transformers are designed to work with valves having an A.C. resistance of approximately 30,000 ohms; if valves having an R_{AC} of much lower value than this are used, selectivity will suffer. On the

other hand, if valves having a higher R_{AC} are used, tuning will be sharper. Naturally,

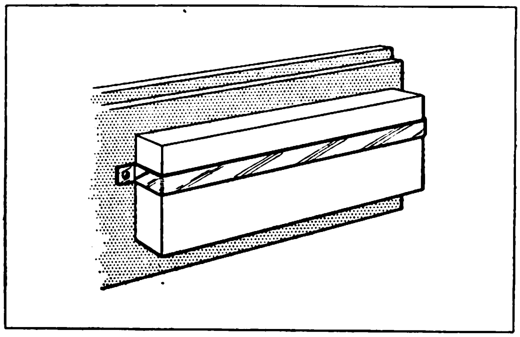


Fig. 6. *Method of fixing grid bias batteries to lid of case.*

for a given value of R_{AC}, the highest amplification factor is required. The valves recommended are Mullard PM5A's for the two high frequency stages, a PM5 for the detector and the first L.F., and a Mullard 256 for the output stage.

The total filament current is 0.65 ampere and used with 120 volts H.T. on all the valves except the detector, which can have about 36 volts, the total anode current is about 18 milliamperes when the grids are properly biased. With this combination of valves it is recommended that two low ratio transformers be used at T_3 and T_4. If maximum volume is required transformer T_4 may be of higher ratio and the output valve may be a PM6. It should be understood that any valves having characteristics similar to those recommended can be used with satisfaction in the receiver.

To balance the H.F. stages is an easy matter; the old-fashioned method of disconnecting one side of the filament circuit of the valve to be balanced is recommended.

Forthcoming Lectures.

A SERIES of six Lectures will be given on "Short Electric Waves Treated Experimentally," by J. H. Morrell, M.A.(Oxon.)—of the Electrical Laboratories, Oxford—at East London College,* Mile End Road, E., commencing on Monday, 7th February, at 6 p.m.

The remaining lectures will be delivered at the same time and place on the five following Mondays.

*Nearest station Stepney Green.

The range of wavelengths to be dealt with is from 200 metres down to 1 metre, and numerous experiments will be demonstrated with the ultra-short waves to show such things as reflection, and measurement of wavelength on Lecher wires.

Amateurs who are interested in short waves will be well advised to attend these lectures, as they will be able to see how to make simple transmitters and receivers, using ordinary valves.

The Delineation of Alternating Current Wave Forms.

By H. A. Thomas, M.Sc.
(of the National Physical Laboratory.)

Introduction.

IN connection with many problems in which distortion is involved it is necessary to compare the input and output wave forms of an amplifier or of a transmitting system. The determination of the wave form given by an amplifier which has a sinusoidal input is a problem which must be solved if an analysis of the distorting members of the system is attempted.

For some time past, in connection with experimental work upon distortion in radio apparatus, including amplifiers, oscillators and modulating arrangements, the output wave form has been investigated, and it is felt that a description of the methods which have been adopted will be of value to those engaged upon similar work.

The simplest method is undoubtedly the application of the Einthoven galvanometer. This apparatus is capable of producing a photograph of waves which do not contain a harmonic higher than a frequency of about 600 per second.

The Use of an Einthoven Galvanometer.

The method of applying this galvanometer to the case of an amplifier output is illustrated diagrammatically in Fig. 1. It will be seen that a pure audio-frequency oscillation is applied to the amplifier input by means of a tuned circuit loosely coupled to an oscillator. The output is passed through the galvanometer and the normal D.C. component of the anode current is balanced out by means of a 2-volt cell and a series resistance. The optical system is shown in Fig. 2 and consists of a powerful arc *A*, an objective at *B*, a microscope at *C*, a cylindrical condensing lens at *D* projecting an enlarged image of the vibrating string on to the camera at *E*. This camera is of the high speed drum type produced by the American Bureau of Standards. It consists of a strip of bromide paper $3\frac{1}{2}$ inches wide and 1 metre long wound once around a drum which rotates at speeds up to six revolutions per second thus giving a peripheral motion of the film of 6 metres per second. The drum has

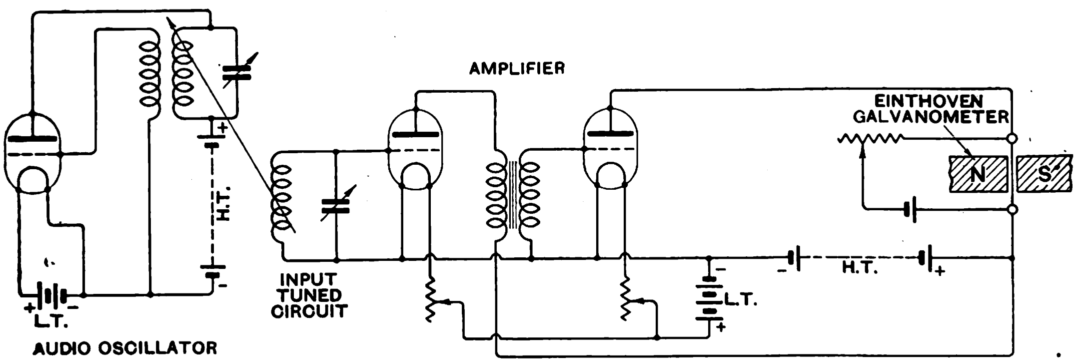


Fig. 1.

a lateral movement imparted by means of a worm which is magnetically locked when the shutter is opened by a local electrical circuit, thus producing a spiral photographic

(c) Gives the same output with zero grid bias.

(d) Gives the same output with 4 volts negative grid bias.

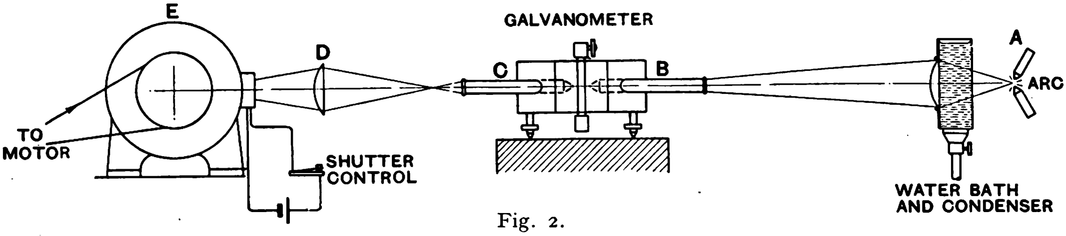


Fig. 2.

record about 3 metres long and 1 inch wide. Sufficient illumination can be obtained to give a very definite record of the movement of the string and examples of the type of record which can be obtained are shown in Fig. 3.

The results given are meant primarily to show the type of record that can be obtained and are not meant to indicate any conditions existing in the amplifier.

The string used can be made either of

Fig. 3 (a).

Fig. 3 (b)

Fig 3 (c).

Fig 3 (d).

(a) Gives the sinusoidal input to an audio-frequency amplifier at a frequency of 160 cycles per second.

(b) Gives the output current of about 0.6 milliamp peak value obtained from this amplifier with 2 volts positive grid bias.

copper about 15μ in diameter or silvered quartz about 5μ in diameter. The latter has a much higher natural frequency and has a much greater resistance, but the optical definition is not so good as with the copper string.

The Use of the Cathode Ray Oscillograph.

For the analysis of frequencies higher than 300 periods per second, the natural frequency and decrement of the moving system are too low, and resort has to be made to the cathode ray oscillograph. The most practical form of oscillograph is the Johnson * tube for a low accelerating voltage, manufactured by the Western Electric Co. The filament of this tube takes about one ampere at 2 volts, and the high tension voltage is 300. The electron stream forming the moving figure may be resolved into a wave with a linear time base, and this can then be harmonically analysed.

The method of using the oscillograph in this way is shown in Fig. 4, the case given being for the determination of the output wave form obtained from an audio-frequency amplifier when the impressed voltage is sinusoidal. The input is applied, as in the previous case, using an Einthoven galvanometer as the recording instrument. The output must be applied to the oscillograph

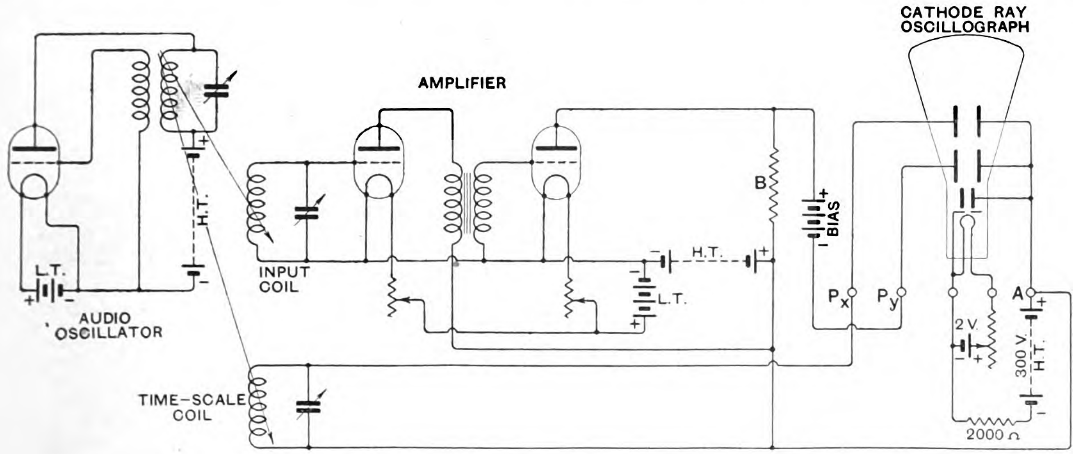


Fig. 4.

element is focused on to the fluorescent screen forming the back of the flask in which the filament, anode and deflecting plates are mounted.

Owing to the low anode voltage employed, the photographic sensitivity of this tube is far poorer than can be obtained with the Dufour 60,000-volt tube, or the Thomson 3,000 volt tube. This means that a single transient wave cannot be photographed and periodic phenomena only can be recorded, in which case a synchronised recurrence of the wave must be obtained giving a definite trace upon the screen. If the sinusoidal input is applied to one pair of plates of the oscillograph and the output is applied to the other pair of plates, the resultant cyclograph obtained will be a Lissajous figure. This in the form of potential and not current. To obtain this potential, a high resistance of 20,000 ohms was inserted in the anode circuit of the output valve, and one pair of plates from the oscillograph was connected across this resistance. To eliminate the normal D.C. voltage existing across this resistance due to the steady anode current component, a battery was inserted in one of the leads as shown at *B*. A record of the figure can be obtained by photographing the back of the flask or by holding bromide paper over the back of the flask. This latter method gives poorer results but is much simpler.

The analysis of the Lissajous figure must now be undertaken. In Fig. 5, let the closed curve represent the observed figure produced on the flask fluorescent screen by the electron stream, and let *AB* and *CD* be the two axes obtained by short circuiting first one and then the other pair of plates. Let *AB* be the time base executing a simple harmonic

* J. B. Johnson, *Physical Review,* 1921, Vol. 17, p. 420; and J. B. Johnson, *Journal of the Optical Society of America*, 1924, Vol. 9, p. 471.

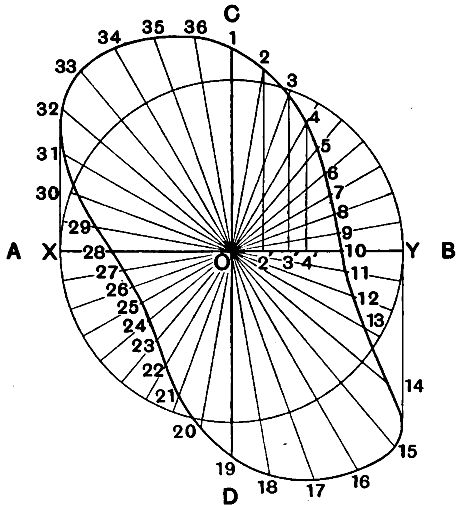
motion about the point O. Draw two perpendiculars from the extremities of the curve on to the horizontal base line AB. The distance OY gives the maximum amplitude of the time scale and OX must equal OY. Now with centre O construct a circle of radius OY. Divide this circle into any

$$y = f(\omega t) = A_0 + A_1 \sin \omega t + B_1 \cos \omega t + A_2 \sin 2\omega t + B_2 \cos 2\omega t + A_3 \sin 3\omega t + B_3 \cos 3\omega t + \ldots$$

where $\omega = 2\pi f$,

and $f =$ frequency.

The terms $(A_1 \sin \omega t + B_1 \cos \omega t)$ form the



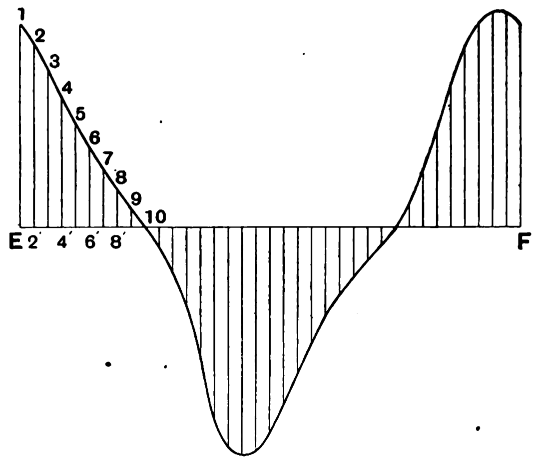


Fig. 5.

number of equal circumferential parts, say every 10 degrees. Join these points to the centre, and produce to meet the closed figure at the points 1, 2, 3, 4, etc. The magnitude of the E.M.F. applied at 10 degree intervals throughout the cycle is given by the perpendicular distance from the points 1, 2, 3, 4, etc., to the time base line AB. Divide a horizontal line EF into 36 equal parts $E1'$, $1'2'$, $2'3'$, etc., each part representing an angle of 10 degrees. Erect vertically the distances $O1$, $22''$, $33''$, etc., from the points E, $1'$, $2'$, $3'$, etc. The locus of the extremities gives the applied wave plotted on a linear time base.

This wave has now to be analysed into its component harmonics. By Fourier's analysis, we know that any periodic function can be split up into a number of sine and cosine terms involving the fundamental frequency, and frequencies of twice, three times, four times this frequency, etc., and if sufficient terms be adopted the wave can be approximated to any required degree of accuracy. Thus the wave can be resolved into the following terms:—

fundamental of the periodic function. This name is given to them because their period is the same as that of the original function (y).

The terms $(A_2 \sin 2\omega t + B_2 \cos 2\omega t)$ form the second harmonic, the fundamental being

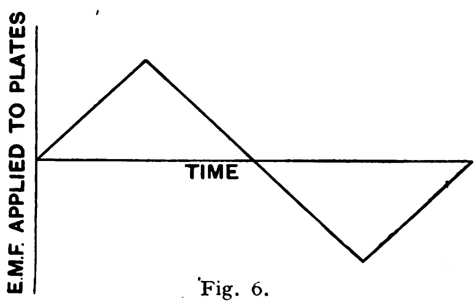


Fig. 6.

the first harmonic. Similarly $(A_3 \sin 3\omega t + B_3 \cos 3\omega t)$ is the third harmonic. The two terms of any harmonic can be combined into a single term, since

$$[A_n \sin n\,\omega t + B_n \cos n\,wt] = C_n \sin (n\,\omega t + \phi_n)$$

where $C_n = \sqrt{A_n^2 + B_n^2}$

$$\sin \phi_n = \frac{A_n}{C_n} \text{ and } \cos \phi_n = \frac{B_n}{C_n}$$

This condition is both necessary and sufficient to evaluate the angle ϕ_n. The value of A_0 can be found by integrating the function (y) over a complete period and dividing by the period, since the integral of a sine and a cosine term over any number of complete periods is zero.

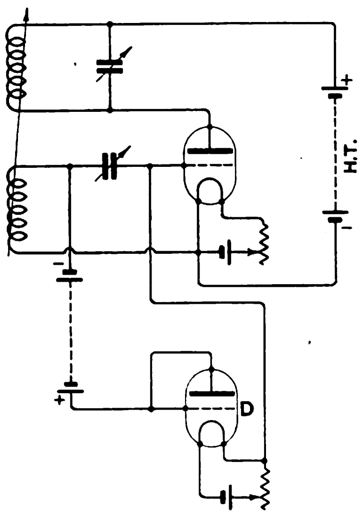


Fig. 7.

Thus to find the value of any other term, use is made of the following definite integrals

(*a*) $\int_0^T (\sin n\ \omega t \sin m\ \omega t)\ dt = 0$

where $T = \frac{2\pi}{\omega}$ = periodic time.

(*b*) $\int_0^T (\cos n\ \omega t \sin m\ \omega t)\ dt = 0.$

(*c*) $\int_0^T \sin^2 m\ \omega t\ dt = \frac{T}{2}$

(*d*) $\int_0^T \cos^2 m\ \omega t\ dt = \frac{T}{2}$

(*e*) $\int_0^T (\sin m\ \omega t \cos m\ \omega t)\ dt = 0.$

If every term of a Fourier's series is multiplied by $\sin m\ \omega t$ and integrated over a complete period, the result is therefore zero, except in the case of the term $A_m \sin m\ \omega t$ which gives $TA_m/2$.

Hence $A_m = \frac{2}{T}\int_0^T y \sin m\ \omega t\ dt.$

Similarly, by multiplying each term by $\cos m\ \omega t$ and integrating, it is found that

$$B_m = \frac{2}{T}\int_0^T y \cos m\ \omega t\ dt.$$

The area of the original wave about the zero axis is determined and divided by the length of the base line for one complete period. This gives the constant term A_0. The wave is now multiplied by $\sin \omega t$ for each 10° degrees and the area of the new curve

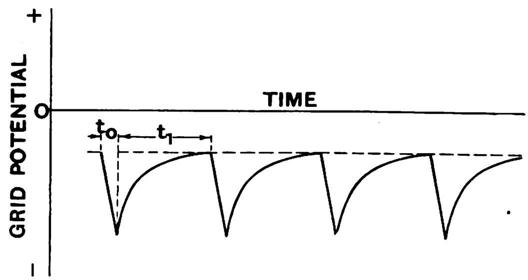


Fig. 8.

so produced is determined and divided by $T/2$ giving A_1. If the cosine curve is drawn, B_1 is determined.

In this way, by multiplying by $\sin 2\omega t$, $\cos 2\omega t$, $\sin 3\omega t$, $\cos 3\omega t$, etc., the values of A_2, B_2, A_3, B_3, etc., are obtained, and the resultant peak values of the harmonics C_1, C_2, C_3, etc., are given by

$$\sqrt{A_1^2 + B_1^2}\quad \sqrt{A_2^2 + B_2^2}\quad \sqrt{A_3^2 + B_3^2}, \text{etc.}$$

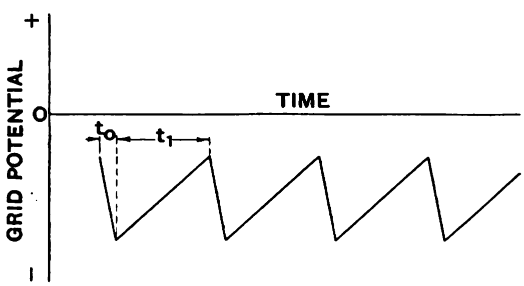


Fig. 9.

The phases are obtained as shown previously and thus the complete wave has been analysed into its constituent parts. The various ordinate methods for analysing waves employed in general electrical problems cannot be used, since these methods assume

the two halves of the wave to be identical and thus neglect the even harmonics.

The Time Base.

The chief difficulty of the method for practical analysis lies in the fact that the general type of wave cannot easily be appreciated until the Lissajous figure has been converted into a linear base wave. If we can produce the wave on a linear base scale directly by the oscillograph, the general types of distortion can be observed, and analysis need only be applied to the special cases of interest.

Various mechanical, optical and electrical devices have been suggested for this purpose, but with a low velocity electron stream as obtained from the Johnson tube, mechanically moved plates and rotating drum methods cannot be applied as the beam has not sufficient actinic value to produce an image with one passage across the plate. We must resort to a time scale consisting of a linear motion and return of the electron stream synchronised with the applied input so that the image is cyclographic. Rogowski* has devised a purely electrical method of producing a uniform periodic motion of the electron stream. A condenser discharge is normally exponential in character if the leak through which the discharge takes place is constant in value. If however the leak resistance is proportional to the E.M.F. existing across it, the discharge is linear, and if the time deflecting plates are connected across the condenser, the beam will be deflected proportional to time. A saturated diode fulfils the necessary conditions, as its current will be constant with varying E.M.Fs. above the saturation value. In one method suggested by Rogowski, two opposed diodes were used and the condenser was alternately charged and discharged with constant current from an alternating source giving a triangular wave form as shown in Fig. 6.

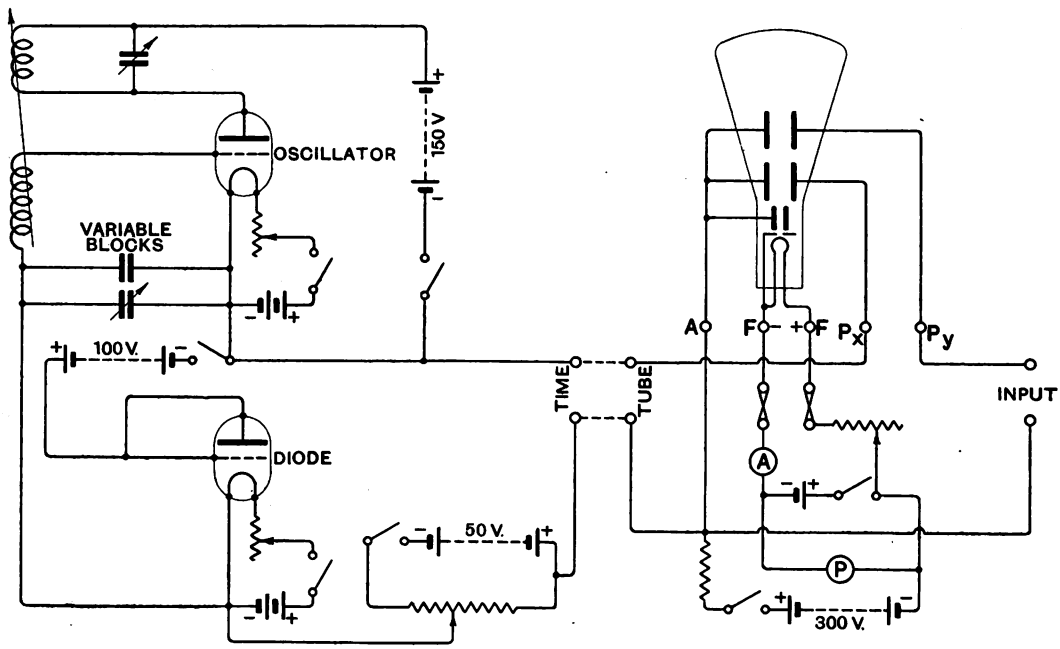


Fig. 10.

A considerable improvement has been produced by E. V. Appleton, R. A. Watson Watt and J. F. Herd,* in which an oscillating triode is used as the generator of the alternating P.D. Referring to Fig. 7 we see that an oscillating system is used with a grid condenser and leak. The leak consists of

* W. Rogowski, *Archiv. für Elecktrotechnik*, 1920, Vol. 9, p. 115.

* British Patent No. 235,254, 11th Feb., 1924

a saturated diode D and the output deflecting voltage is taken from the grid condenser terminals. If the leak were constant in value we should have grid potential variations in terms of time as shown in Fig. 8.

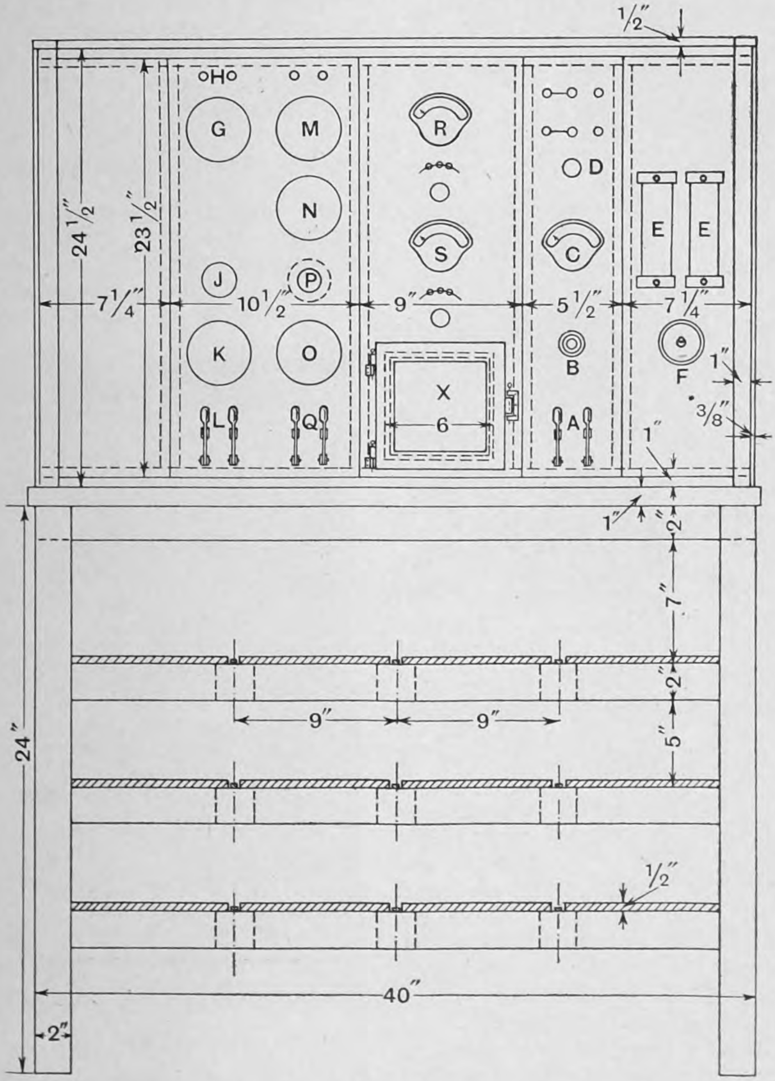


Fig. 11.

As the oscillations continue, the condenser becomes charged and the grid is rapidly depressed in voltage during the period t_0.

The grid is now so negative that the oscillation stops and the condenser discharges exponentially giving a grid voltage characteristic as shown during the time t_1. When the potential is sufficiently restored due to this leaking action, the oscillation again starts and we shall obtain a recurrence of the phenomena.

Now using a saturated diode for the leak, the discharge is linear (since the resistance is proportional to the E.M.F. applied) and we get the characteristic depicted in Fig. 9. The frequency of this discharge can be altered by means of the grid condenser, which is variable and the leak resistance which can

be controlled by the filament rheostat of the diode, and if this frequency is a sub-multiple of the incoming wave applied to the other pair of plates, a recurrence of the time scale will duplicate the oscillogram and give a cyclographic record of as many waves as we please. Usually it is preferable to

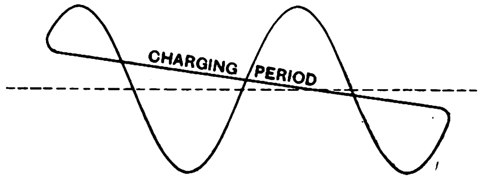


Fig. 12.

arrange that the time scale frequency is synchronised to one-half that of the incoming wave, thus giving two complete waves on the oscillograph screen. The period of charging the grid condenser will depend upon the main oscillator frequency and if this is high, the time of charging is about one-tenth of the time for leakage, *i.e.*, in Fig. $9 t_1/t_0 \doteqdot 10$.

The necessary condition is that the insulation of the grid condenser be very good. If a small constant shunt leak exists, the time scale cannot be made linear. The method has been adopted for the recording of wave forms of frequencies ranging from 30 p.p.s. to 1,000,000 p.p.s., and it is felt that a description of the apparatus may be of value to others engaged in similar types of work. The complete circuit diagram is shown in Fig. 10. The two deflecting plates are A & P_X and A & P_Y. A & P_Y are connected to the input terminals and A & P_X to the tube terminals. These are connected by links to the timing mechanism. Switches are provided in the low and high tension circuits, and an ammeter in the filament circuit of the oscillograph. To give a static bias to the time scale plates to compensate for the normal negative potential existing across the grid of the oscillating triode, a potentiometer is connected in series with these leads.

The voltages of the three high tension batteries can be read by means of a voltmeter and the low tension batteries can also be tested in a similar manner.

The frequency of the time base is regulated by a fine drum type rheostat in the filament of the diode, and by block condensers and a vernier condenser acting as the grid condenser. The frequency of the oscillator is about 10^6 p.p.s., the high tension battery voltage being 150 using a T15 valve. The diode consists of a dull emitter valve with the grid connected to the anode and 100 volts high tension. The oscillograph filament takes 1 ampere at 2 volts and the anode is applied with 350 volts.

The Complete Equipment.

The controlling apparatus is panel mounted, as shown in Fig. 11, which gives a detailed drawing of the complete assembly. The oscillograph tube is mounted in a wooden

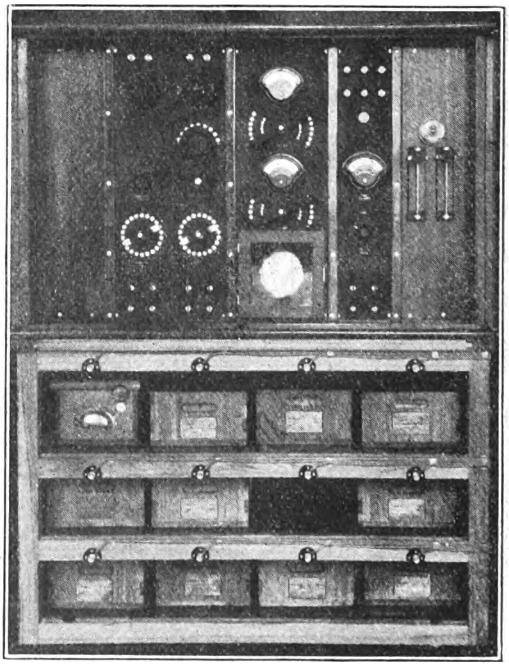


Fig. 13.

case with a window for protection as shown at X. The right hand panel controls the oscillograph and has a main switch A, rheostat B, ammeter C, and pilot lamp D. The static balancing potentiometer is shown at E with switch F. The oscillator control is mounted on the left side of the left panel and consists of a variable condenser G with terminals H for extra capacity, a coupling

control *J*, a coarse filament rheostat *K* and switch *L*. The diode controls are on the right hand side of this panel and consist of a variable condenser *M*, small fixed condensers *N*, a coarse filament rheostat *O*, a fine rheostat *P*, and a main switch *Q*. The high tension and low tension voltages are tested by means of the voltmeters and switches *R* and *S* respectively. Normally the terminals "*Time*" and "*Tube*" are connected together and the wave to be analysed is applied to the terminals marked "*Input*."

The voltage sensitivity of the oscillograph is about 1 mm. deflection per volt. The input required to give a figure 2 cms. high is therefore 20 volts and a figure of this size can be analysed with fair accuracy. The image is photographed and the negative is enlarged to about 2 feet square and traced. This figure can then be analysed harmonically. Fig. 12 gives a sketch of the image obtained with a sinusoidal input and shows the short return during the charging period of the leaky condenser.

The high tension supply consists of three separate insulated batteries of 350, 150 and 100 volts respectively. These are built of 50-volt accumulator units and each battery stands on glass. To charge these batteries without removal from their stand, a special switch is used mounted on the side of the battery stand. This switch isolates the three banks in the working position and puts all the batteries in parallel in the "*Charge*" position to be connected to 100-volt mains.

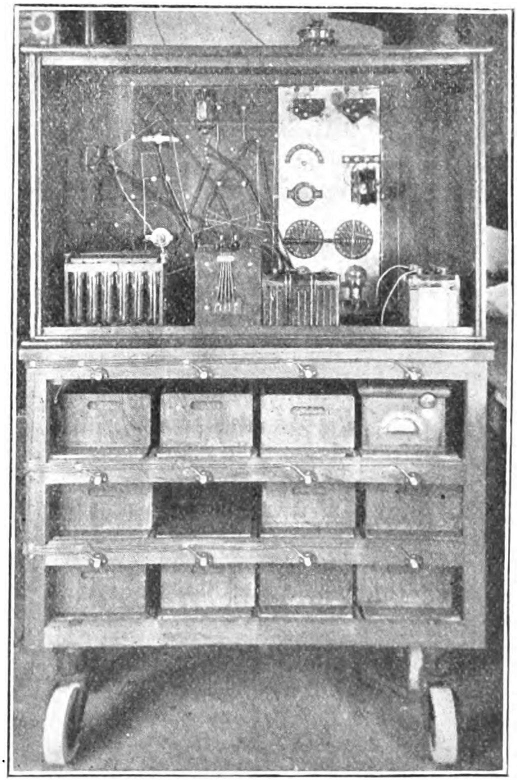


Fig. 14.

A photograph of the complete apparatus is shown in Fig. 13 and a view of the back of the panel in Fig. 14.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 762 *of December issue.*)

6. The Solution of Equations.

(c) *Simultaneous Equations for Several Unknown Numbers.*

It has already been indicated that if several unknown numbers have to be determined an equal number of separate and independent equations will be required. A perfectly general discussion of m equations of the nth degree would take the writer out of his depths and bore the reader intolerably, besides wasting his time. The solution of several first degree equations for an equal number of unknowns is, however, quite another matter, for it is comparatively simple and of great practical importance in applied electricity. As already mentioned, such equations arise from the application of Kirchhoff's Laws to direct or alternating current networks, and are therefore of particular interest to wireless amateurs.

To save time, space, and trouble the representative example of three equations for three unknowns will be considered. It will be found that the method is the same as that which has been applied to the solution of two equations for two unknowns. The method is, in fact, capable of indefinite extension. Take as the equations

$$x+2y+3z=4 \quad \ldots \quad (1)$$
$$2x+3y+4z=5 \quad \ldots \quad (2)$$
$$3x+6y+7z=6 \quad \ldots \quad (3)$$

Multiply (1) by 4 and (2) by 3 in order to make the coefficients of z the same in each.

$$4x+8y+12z=16 \quad \ldots \quad (4)$$
$$6x+9y+12z=15 \quad \ldots \quad (5)$$

and by subtracting (4) from (5),

$$2x+y=-1 \quad \ldots \quad (6)$$

Another equation in x and y can be obtained from equations (2) and (3) in a similar manner, or from (1) and (3) if this is preferred for any reason. Multiplying (2) by 7 and (3) by 4,

$$14x+21y+28z=35 \quad \ldots \quad (7)$$
$$12x+24y+28z=24 \quad \ldots \quad (8)$$

and subtracting (8) from (7)

$$2x-3y=11 \quad \ldots \quad (9)$$

Also from (6)

$$2x+y=-1 \quad \ldots \quad (6)$$

In this case it happens that the coefficients of x are the same in these two equations. If they were not the same operation would induce them to be so. As it is we can avail ourselves of their accommodating disposition by simply subtracting (6) from (9), giving

$$-4y=12 \quad \ldots \quad (10)$$

or

$$y=-3 \quad \ldots \quad (11)$$

Substituting this value for y in (6),

$$2x-3=-1 \quad \ldots \quad (12)$$

or

$$x=1 \quad \ldots \quad (13)$$

Now, putting $x=1$ and $y=-3$ in (1)

$$1-6+3z=4 \quad \ldots \quad (14)$$

Therefore

$$z=3 \quad \ldots \quad (15)$$

and, rounding them up, we have as the simultaneous solutions of the three equations

$$x=1$$
$$y=-3$$
$$z=3$$

It may be pointed out as a matter of interest that the cartesian diagram already considered in its simplest form with the two x and y axes at right angles to each other can be completed by the addition of a third or z axis at right angles to both, like the adjacent edges of a cube. Three co-ordinates, x, y, and z will then define a point in space, just as two co-ordinates define a point in a plane in the simpler plane diagram. Further, just as

$$ax+by=c$$

defines a line in the x, y plane, so

$$ax+by+cz=d$$

defines a plane in space. The solution obtained above for the three plane equations gives the co-ordinates of a point common to the three planes, *i.e.*, the point of intersection of the three planes If we could comprehend

a fourth dimension the first degree equation in four unknowns could be similarly interpreted, but unfortunately (or perhaps fortunately) the mind budges like a mule at the prospect and refuses to carry us further, so there we have to leave the geometrical aspect of the matter.

That, however, would not prevent us from solving four such equations for four unknowns. From any two, one of the unknowns can be eliminated. From three different pairs the same unknown can be eliminated three times, giving three equations for three unknowns, which can be solved as above. And so on for any given number of unknowns.

To show how such equations can arise from the application of Kirchhoff's Laws to a network, let us write down the equations for the system shown in Fig. 14, which the reader will recognise as a Wheatstone bridge. The equations are

$$\begin{aligned} e-Bi_1-R(i_1-i_2)-S(i_1-i_3)&=0\\ R(i_2-i_1)+Pi_2+G(i_2-i_3)&=0\\ G(i_3-i_2)+Qi_3+S(i_3-i_1)&=0 \end{aligned}$$

which can be re-arranged rather more tidily as

$$\begin{aligned} (B+R+S)i_1 \quad -Ri_2 \quad -Si_3&=e\\ -Ri_1+(R+P+G)i_2-Gi_3&=0\\ -Si_1 \quad -Gi_2+(G+Q+S)i_3&=0 \end{aligned}$$

The reader is strongly advised to solve these equations for the three currents i_1, i_2, i_3, but is warned to secure largish sheets of paper for the purpose, owing to the unrestrained prolixity of literal expressions. In the present instance particular interest attaches to the current through the branch of resistance G, which represents the resistance of a galvanometer or similar measuring instrument. The reader should be able to show that this current, *i.e.*, i_2-i_3, is given by

$$i_2-i_3=(RQ-SP)e/K$$

where K is the simple but voluminous expression

$$\begin{aligned} K=BGP+BGQ+BGR+BGS+PQR+\\ PQS+PRS+QRS+GPR+GQS+GPS+\\ +GQR+BPQ+BRS+BSP+BRQ. \end{aligned}$$

This shows that the current through G will be zero when

$$RQ-SP=0$$

i.e., when $\left(\dfrac{P}{Q}=\dfrac{R}{S}\right)$

which is the well-known balance condition for the simple resistance bridge.

Later on it will be found that even the most complicated networks carrying alternating currents can be similarly analysed, though for this purpose several additional ideas will be required, some of which will be introduced in the next section.

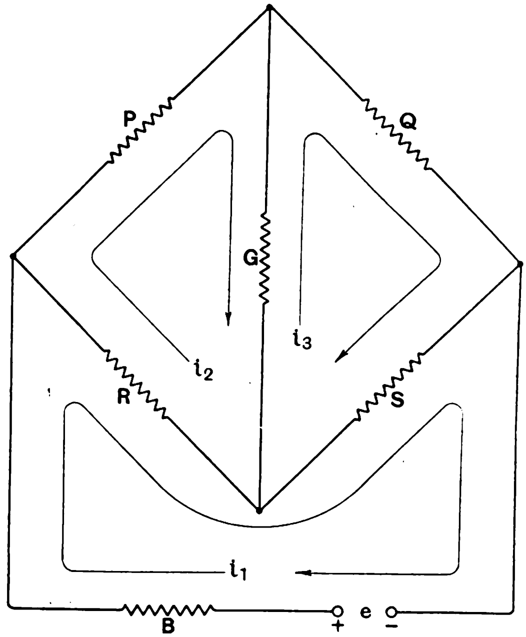


Fig. 14.

7. Complex Numbers.

(A) *The Symbol "i"*

The reader has already a bowing acquaintance with $\sqrt{-1}$, and has possibly decided that this somewhat perplexing symbol, being devoid of that comfortable and concrete reality that attaches to real numbers, is not likely to count for much in practical politics. Associated with this symbol, however, are certain ideas which will eventually prove to be of very great value in connection with alternating current problems, so time will not be ill-spent in cultivating a somewhat closer acquaintance. It is, moreover, an intrinsically interesting symbol, and, under the pet name of "i" enjoyed what Prof. Whitehead described as a *succès de scandale* when it first made its appearance in mathematics.

At present all we know about it is the definition

$$\sqrt{-1}\times\sqrt{-1}=i\times i=i^2=-1$$

and it is worth noting that this definition

assumes the possibility of associating the symbol i with the idea of multiplication, so that $ai \times bi$ for instance, can be taken to mean

$$a \times i \times b \times i = a \times b \times i \times i = abi^2 = -ab$$

This is an instance of that possibility envisaged in para. C3 of Section 3 (June, 1926), where ideas in themselves incomprehensible can be employed without violating one's intellectual self-respect, it being understood that any such incomprehensible operations stand not on their own merits but on the validity of the conclusions they lead to.

(B) *Addition of Complex Numbers.*

A group, such as $a+bi$ (or $a+ib$—it does not matter which way it is written), is called a complex number. Such numbers have been met with in the solution of quadratic equations in the preceding section. Such complex numbers can be compared with the "double groups" referred to in para. A2 of Section 3 (May, 1926), and in the addition of such complex numbers the same ideas will apply. That is to say, in $a+ib+c+id$, the numbers a and c can be added arithmetically, and the b i's can be added to the d i's, giving $(b+d)i$'s, so that

$$a+ib+c+id=(a+c)+i(b+d)$$

for instance

$$3+i4+7+i8=10+i12$$

and, of course, similarly for subtraction. In particular

$$(a+ib)+(a-ib)=2a$$
$$(a+ib)-(a-ib)=2ib$$

The first of these statements involves the idea that $i(b-b)$, *i.e.*, $i \times 0$ is 0, which is seen to be quite reasonable if $i \times 0$ is regarded as $\sqrt{-0}$, for -0 is by definition the same as $+0$.

(C) *Consider the statement*—

$$a+ib=0$$

where a and b are real numbers. Subtracting ib from each side gives

$$a=-ib$$

But this is a contradiction in terms, for a is a number and ib is not. To make this clearer, squaring each side would give

$$a^2=(-ib)^2=(ib)^2=i^2 \times b^2=-1 \times b^2=-b^2$$

which is impossible since both a^2 and b^2 are necessarily positive numbers, whatever the signs of a and b may be. However the statement $a=-ib$ is not completely impossible, because it is true if both a and b are zero, *but only in this case.* The statement

$$a+ib=0$$

therefore implies $a=0$ and $b=0$

Further, if we are given that

$$x+iy=a+ib$$

subtracting $a+ib$ from each complex number will give

$$(x-a)+i(y-b)=0$$

so that $(x-a)=0$ and $(y-b)=0$

or $x=a$ and $y=b$

The original equation is therefore really equivalent to two separate equations. This process is referred to as equating the real and the imaginary parts.

(D) *The Multiplication of Complex Numbers.*

On the above understanding (para. A) with respect to the association of i with the idea of multiplication, the multiplication of complex numbers follows the ordinary rules, *i.e.*,

$$\begin{aligned}(a+ib)(c+id) &= ac+ibc+aid+ibid \\ &= ac+ibc+iad+iibd \\ &= (ac-bd)+i(bc+ad)\end{aligned}$$

In particular

$$(a+ib)(a-ib)=a^2+b^2$$

Two complex numbers such as these, differing only in the sign of the imaginary part, are said to be mutually conjugate. Notice that the sum and the product of conjugates are wholly real. Notice further that in general the sums or products of complex numbers are other complex numbers, so that if $f(x)$ be any built-up number composed of various integral powers of x associated with constant coefficients (*cf.* the general equation of the nth degree), then if x be given a complex value $(a+ib)$, $f(a+ib)$ will be a complex number, *i.e.*,

$$f(a+ib)=P+iQ$$

just as $f(x)$ is a real number if x is given any real value.

(E) *The Modulus of Complex Numbers.*

The modulus of $(a+ib)$ is the positive value of the square root of (a^2+b^2), *i.e.*,

$$mod.(a+ib)=\sqrt{a^2+b^2}$$

For instance, the modulus of $(12+i5)$ is $\sqrt{12^2+5^2}$, *i.e.*, 13. Notice that the modulus of a complex number is the same as that of its conjugate.

A very useful property of moduli is that the modulus of the product of two complex numbers is the same as the product of their moduli. This is easily proved, for

$$\begin{aligned} mod.(a+ib)(c+id) &= mod.(ac-bd)+i(bc+ad) \\ &= \sqrt{(ac-bd)^2+(bc+ad)^2} \\ &= \sqrt{a^2c^2+b^2d^2+b^2c^2+a^2d^2} \\ &= \sqrt{(a^2+b^2)(c^2+d^2)} \\ &= \sqrt{(a^2+b^2)}\sqrt{(c^2+d^2)} \\ &= mod.(a+ib)\times mod.(c+id) \end{aligned}$$

This can obviously be extended to the product of any number of complex numbers and thence to integral powers of complex numbers, so that

$$mod.(a+ib)^n=\{mod.(a+ib)\}^n=$$
$$\{\sqrt{a^2+b^2}\}^n=(a^2+b^2)^{n/2}$$

Further, this can be shown to be true for negative or fractional values of n,

e.g., let $\quad (a+ib)^{\frac{1}{m}}=P+iQ$

Then, from the definition of the fractional index

$$(a+ib)=(P+iQ)^m$$
$$mod.(a+ib)=mod.(P+iQ)^m=$$
$$\{mod.(P+iQ)\}^m=\{\sqrt{P^2+Q^2}\}^m$$

Therefore $\quad \sqrt{a^2+b^2}=\{\sqrt{P^2+Q^2}\}^m$

whence $\quad \{\sqrt{a^2+b^2}\}^{\frac{1}{m}}=\sqrt{P^2+Q^2}$

or $\quad \{mod.(a+ib)\}^{\frac{1}{m}}=mod.(a+ib)^{\frac{1}{m}}$

and similarly for the general fractional index and for negative indices. The modulus of a more or less complicated complex number can thus be written down at sight. For instance,

$$mod.\frac{(a+ib)^m(c-id)^{p/q}}{(e+if)^r}=\frac{\sqrt{\{a^2+b^2\}^m\{\sqrt{c^2+d^2}\}^{p/q}}}{\{\sqrt{e^2+f^2}\}^r}$$

Is the modulus of the sum of two complex numbers the same as the sum of their moduli? It isn't, but the reader is advised to prove this for himself.

(F) *Application to the General Equation of the nth Degree.*

Complex numbers were first encountered in connection with the solution of quadratic equations, and it was indicated that they would also occur in the solution of the general equation of the **n**th degree. It was further stated that complex roots would always occur in pairs (of conjugates). This can now be proved quite simply. First it is required to show that if

$$(a+ib)^n=P+iQ$$

then $\quad (a-ib)^n=P-iQ$

If $\quad (a+ib)^n=P+iQ$

$$\frac{1}{(a+ib)^n}=\frac{1}{P+iQ}$$

therefore $\quad \dfrac{(a-ib)^n}{(a+ib)^n(a-ib)^n}=\dfrac{(P-iQ)}{(P+iQ)(P-iQ)}$

i.e., $\quad \dfrac{(a+ib)^n}{\{(a+ib)(a-ib)\}^n}=\dfrac{(P-iQ)}{P^2+Q^2}$

or $\quad \dfrac{(a-ib)^n}{(a^2+b^2)^n}=\dfrac{P-iQ}{P^2+Q^2}$

But since

$$(a+ib)^n=P+iQ,\ (\sqrt{a^2+b^2})^n=\sqrt{P^2+Q^2},$$

as shown above, so that

$$(a^2+b^2)^n=P^2+Q^2$$

Therefore $\quad (a-ib)^n=P-iQ$

Consider now the general equation of the **n**th degree, *i.e.*,

$$f(x)=ax^n+bx^{n-1}+cx^{n-2}+dx^{n-3}+\text{etc.}\dots k=0$$

For any complex value $(\alpha+i\beta)$ of x each separate power of x will give rise to a complex number of the form $P+iQ$, and the sum of all these will be some complex number, say, $M+jN$. It obviously follows from the above that for the conjugate value $(\alpha-i\beta)$ for x, the sum of all the separate terms will be $M-jN$, *i.e.*, if

$$f(\alpha+i\beta)=M+jN$$
$$f(\alpha-i\beta)=M-jN$$

Now suppose that $(a+i\beta)$ is known to be a root of the equation, so that

$$f(\alpha+i\beta)=M+jN=0$$

Then, from para. C of this section,

$$M=0 \text{ and } N=0$$

so that $\quad f(\alpha-i\beta)=M-jN=0$

Therefore $(\alpha-i\beta)$ must also be a root of the equation.

(G) *The Square Root of a Complex Number.*

If $x+iy$ be the square root of $a+ib$, then, by definition,

$$(x+iy)^2=a+ib.$$

For many purposes it will be necessary to know x and y in terms of a and b, *i.e.*, to find the real and imaginary parts of $(a+ib)^{\frac{1}{2}}$. It can be done in this way. Multiplying $x+iy$ by itself as shown in para. D.

$$(x+iy)^2=(x+iy)(x+iy)=$$
$$x^2-y^2+2ixy=a+ib$$

therefore, as shown in para. C,

$$x^2-y^2=a$$
and $$2xy=b$$

These two equations can be solved for x and y by methods already described. In this particular case, however, the work can be shortened by making use of the fact that the square of the modulus of $x+iy$ will be equal to the modulus of $a+ib$ (see para. E), so that

$$x^2+y^2=+\sqrt{a^2+b^2}.$$

For shortness, and also to avoid typographical complication later on, we will write r for $+\sqrt{a^2+b^2}$, so that we have the two equations

$$x^2+y^2=r$$
$$x^2-y^2=a$$

whence, by addition and subtraction,

$$x^2=\tfrac{1}{2}(r+a)$$
$$y^2=\tfrac{1}{2}(r-a)$$

i.e.,
$$x=\pm\sqrt{\tfrac{1}{2}(r+a)}$$
$$y=\pm\sqrt{\tfrac{1}{2}(r-a)}$$

Thus x and y are determined. In the matter of signs we seem to have an *embarras de richesse*, but the apparent superfluity can be disposed of in this way: Since $2xy=b$, x and y must be of the same sign if b is positive and *vice versa*. Therefore if b is positive

$$\sqrt{a+ib}=\pm\{\sqrt{\tfrac{1}{2}(r+a)}+i\sqrt{\tfrac{1}{2}(r-a)}\}$$

and if b is negative

$$\sqrt{a+ib}=\pm\{\sqrt{\tfrac{1}{2}(r+a)}-i\sqrt{\tfrac{1}{2}(r-a)}\}$$

To take a simple example, consider $\sqrt{3+i4}$. Here a is 3 and b 4, so that r is $+\sqrt{9+16}=5$, $r-a$ is 2 and $r+a$ is 8.

Therefore

$$\sqrt{3+i4}=\pm\{\sqrt{\tfrac{1}{2}\times 8}+i\sqrt{\tfrac{1}{2}\times 2}\}$$
$$=\pm(2+i)$$

and if the reader has any doubts about it he can square $\pm(2+i)$ to make sure.

There is a peculiar fascination about the subject of complex numbers, but this, unfortuntaely, is all the space that can be allowed for it at present. Once more the reader is cautioned against dismissing the subject as academic on the grounds that an imaginary quantity cannot have any practical significance. Though academic in appearance, these same ideas can, as it were, doff hood and gown and set about a job of real work with a pick and shovel. We shall see them at it later on.

Examples.—Simultaneous Equations for Several Unknowns.

1. Solve the equations :—

(a) $x+y+z=12$
$x+2y+3z=26$
$3x+2y+z=22$

(b) $x+y=2z$
$5x+4y+3z=12$
$21x-20y-2z=-1$

(c) $43x+19y+10z=100$
$100x+y-3z+30=0$
$x-y+z=10$

2. Solve :—

$w+x+y=6$
$2x+3y+4z=29$
$4y+2z-3w=17$
$8z-5w+7x=41$

3. Solve the equations :—

$mx+ny+z=(1+m+n)a+(3+m+n)b$
$2x+3y-5z=-7b$
$5x+8y-7z=6a$

Complex Numbers.

4. Show that :—

$$\frac{a+ib}{c+id}=\frac{ac+bd}{c^2+d^2}+i\,\frac{bc-ad}{c^2+d^2}$$

5. Find the moduli of :—

(a) $\dfrac{(3+i)(7-i)}{(2-i)}$

(b) $\dfrac{(3-4i)}{(3+4i)}+\dfrac{(12-5i)}{(12+5i)}$

6. Show that :—

$$\sqrt{i}=\pm(1+i)/\sqrt{2}$$
$$\sqrt{-i}=\pm(1-i)/\sqrt{2}$$

and hence show that the eight eighth roots of unity are :—

$$\pm 1,\ \pm i,\ (1\pm i)/\sqrt{2},\ \pm(1-i)/\sqrt{2}$$

Answers to Examples in December Issue.

(1) $-2, 9, -3$.

(2) $1-2i$, $1+2i$, 4, 30.

(3) 0.

(4a) $x=1$, $y=81$.

(4b) $x=.62$, $y=.18$.

(5a) $x=3, y=2$; $x=2$, $y=3$.

(5b) $x=1$, $y=3$; $x=-1\tfrac{1}{5}$, $y=-3\tfrac{3}{5}$; $x=-3$, $y=3$; $x=2$, $y=-2$.

(5c) $x=4$, $y=3$; $x=-4$, $y=-3$; $x=\dfrac{7\sqrt{3}}{2}$, $y=-\dfrac{5\sqrt{3}}{6}$; $x=-\dfrac{7\sqrt{3}}{2}$; $y=\dfrac{5\sqrt{3}}{6}$.

Quartz Crystals and their Practical Application to Wireless Circuits.

A Paper read before the Radio Society of Great Britain, on 24th November, 1926, by A. HINDERLICH, M.A.

The phenomena of the piezo-electric quartz are considered with special reference to radio transmitting stations. The technique of accurate grinding is described. Several control circuits for low and high power transmitters are given.

I.—Historical.

IN 1880, P. and J. Curie* discovered that a plate of cut quartz, when stretched, acquired a charge upon the surfaces.

In 1922, Cady† published his paper on "The Piezo-Electric Resonator," which contained sufficient practical information about oscillators to stimulate amateur research.

Since the end of 1925, most issues of *Q.S.T.* have contained some reference to quartz control as applied in amateur practice in America.

In 1926, Goyder‡ published the first account of a complete station suited to English practice, and Dye§ gave his classical paper on the theory of the resonator.

II.—Properties of Quartz.

Although a use may be found for almost any piece of quartz whose faces are approximately flat and parallel, it is most essential, in order that consistent results may be secured, for great attention to be paid to certain practical rules.

In Fig. 1 the outline represents a section across a natural quartz crystal at right angles to the optic axis. The dotted lines are representative axes. Any line at right angles to the sides, or parallel to the sides, is an axis.

A rectangular plate cut as shown at *A* will have three dimensions, one parallel to the sides, one at right angles to the sides, and one parallel to the optic axis. (If the cut be oblique, or if the crystal be an optical twin, all manner of components will be involved.) Oscillations may take place, according to Hund,* along all these axes, at three different fundamentals. A rough approximation is :—

$$\lambda \text{ (metres)} = \left\{\begin{matrix}\text{Dimension in}\\ \text{millimetres}\end{matrix}\right\} \times 105 \text{ or } 150$$

Hund has determined the three fundamentals and their corresponding harmonics for a set of similar resonators. When used as oscillators, I find, as a general rule, that it is exceedingly difficult to obtain more than one fundamental (accompanied of course by its harmonics) out of a given specimen of quartz.

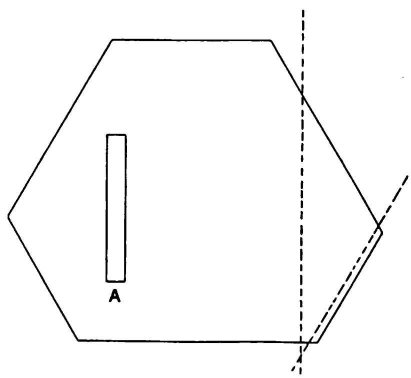


Fig. 1.

Whilst oscillating, the quartz plates expand and contract by a few millionths of an inch. It is a common experience for an oscillator to give a reduced output after a while, which

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* *Comptes Rendus*, 91, pp. 294, 383.

† *Proc. Inst. Radio Engineers*, New York, April, 1922.

‡ *E.W. & W.E.*, February and March, 1926.

§ *Proc. Physical Society of London*, August, 1926.

* *Proc. Inst. Radio Engineers*, New York, August, 1926.

can be cured by tapping the holder, and so shifting the contact to a different position. That is the practical remedy—the theoretical one would be to avoid friction by making contact at an antinode. This can be effected in two ways. The first is to balance the quartz on edge between vertical electrodes, so that the motion of the quartz is chiefly vertical. The second is to have the electrodes horizontal, but only in contact at an antinode. While very difficult in theory, the desired result may be readily secured by exploration with electrodes that are not quite flat, but provided with a slight projection in the middle. The best position is found while watching the output. Another remedy is the cork tripod as used by Dye.

According to Clayton,* the 150-metre per millimetre cut of quartz shows the maximum piezo-electric effect, with slight temperature co-efficient, while the 105-cut yields crystals with slightly lower piezo-electric effects, but with zero temperature co-efficients.

Grinding may easily be performed in the following manner. Upon a sheet of clean, flat glass is placed some thin paste of abrasive and water. The finger-tips are placed upon the quartz firmly, so as not to scratch the upper surface with loose abrasive. Either of the sequences shown in Fig. 2 may be followed to give an equal amount of grinding to each part of the quartz. The diagram shows the plate as stationary, but in practice a right-handed man would rotate the quartz clockwise through 45 deg. after applying the finger-tips.

The quartz should be moved all over 30 square inches of glass surface or more, with a gentle pressure to allow a supply of abrasive to come underneath, alternating with heavy pressure to perform the actual grinding. With crystals of over 90 metres, pressures over 8 ounces are quite permissible.

With each grade of abrasive, the work should finish in time to allow of at least one minute's work with the succeeding grades.

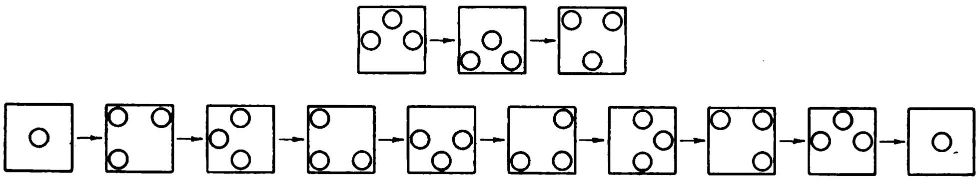


Fig. 2.

III.—Manipulation.

The cutting of quartz plates out of the rough has been described by Cady, Goyder and others. It is a most laborious task, not to be lightly undertaken without the full mechanical and optical equipment.

By improving the polish of the surfaces, an improvement in oscillating properties may be expected. As the user will often wish to effect a small reduction in the wavelength of his specimen, the process will now be described in some detail.

The most useful abrasives, together with the rate of reduction of wavelength using safe pressure, are listed below :—

Carborundum F .. 2 metres per minute
Carborundum 3F .. 1 metre per minute
Sira (putty) powder ½ metre per minute
Rouge, jeweller's.
Rouge, precipitated.

It will not be possible to use rouge upon glass. To obtain a brilliant polish, the quartz is stuck upon a firm support (such as a sheet of flat glass) with wax, and then the rouge is applied upon a cork or leather pad. This method may also be used for grinding, as there is little or no danger of fracture, but there is a greatly increased chance of grinding the plate wedge shape.

Although a quartz plate *may* function quite well though the thickness vary as much as 25 per cent., it will probably work better if the thickness be the same all over (both faces plane and parallel). One often finds that after removing a high spot by local grinding the wavelength is scarcely affected, but it also happens that what was intended to be a slight reduction proves to be a serious one. This experience is quite common with crystals below 60 metres, as they are sufficiently flexible to allow of half a thousandth of an inch being taken off

* *T. & R. Bulletin*, September, 1926.

wherever required by simple local pressure with a finger-tip.

On testing out the crystal with a small top electrode, two spots may be found, well separated, each giving a large output but slightly different wavelengths owing to local variations in thickness. Such specimens are best divided so as to give one good spot in each piece. The method is to back the

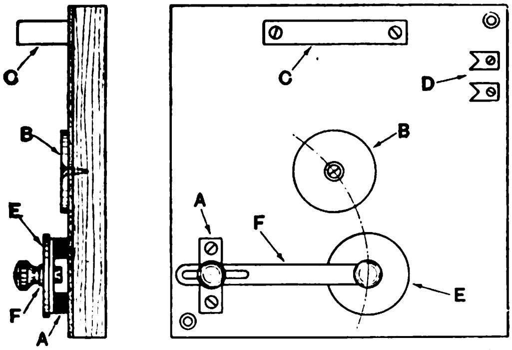


Fig. 3.

quartz with glass and wax, score deeply along the desired line with a glazier's diamond, stick each portion on to a separate piece of glass, and then snap along the scored line.

IV.—Mountings.

An experimental mounting is best constructed according to Fig. 3. A dry wood block, at least 5 in. square, is screwed to the bench. Upon it is placed a piece of felt or velvet of similar size. Then the components sketched are screwed to the wood through the cloth: A is an insulated knob and screw, held away from the cloth by an insulating block; B is the bottom electrode (which for rectangular quartz is preferably of rather smaller diameter than the diagonal) provided with a connecting lead soldered to the underside. It is best attached by a woodscrew, taking great care that neither screw nor burrs project; C is a simple distance-piece that may be wanted later to apply pressure; E is the top electrode complete with screw. Several of these of different sizes and weights should be provided. Another insulated knob fixes the top electrode to F which is a strip of thin copper foil, reinforced at the ends and provided with a round hole to take E and a slot to fit A and so enable the top electrode to be held in any position relative to the quartz; D are two corner pieces to hold the quartz in the correct position, and cannot be fixed till later.

Such a mounting will often serve for continuous use when provided with a stout lid. A permanent mounting can only be designed when the idiosyncrasies of the particular quartz specimen have been determined.

V.—Quartz Resonators.

Such an exhaustive account of this subject has already appeared in Dye's classical paper before the Physical Society of London, that only a bare outline of the method will be given here. The fundamental circuit is that shown in Fig. 4.

Current from a variable source flows in the coil L which is coupled to the tuned circuit L_1C_1, with which is associated the mounted quartz and a current measuring device.

On taking the resonance curve (*i.e.*, frequency plotted against current), a steep crevasse appears at the quartz response frequency. From the shape of the crevasse, Dye deduces the damping of the quartz, and the exact response frequency to an accuracy of one part in ten million.

A less sensitive but more robust method developed in Germany utilises the rise in voltage across the quartz at resonance to produce a luminous glow in rarefied neon gas.

For everyday measurements, the circuit can be used as a simple absorption wavemeter by dispensing with the condenser and the current measuring device. It is often sufficient, as was pointed out by Goyder, merely to lay the unmounted quartz on one of the coils of an oscillating receiver to get the characteristic ringing clicks whenever the receiver frequency passes through a quartz harmonic.

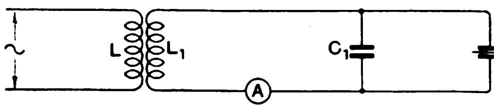


Fig. 4.

It should be noted that resonators only give the average frequency variation over a considerable period of time (say $\frac{1}{16}$ second). They would not even indicate the commonest source of trouble with transmitters (frequency modulation of plate supply) for which quartz, properly applied, is a certain cure.

VI.—Quartz Oscillators.

Quartz, when made to control the frequency of transmitting stations, will revolutionise the technique of radio engineering on account of the vastly increased steadiness of the emitted wave thereby afforded. This is only possible on account of the fact that the vibrations are purely mechanical, and thus of a totally different nature to the electrical vibrations hitherto used, and hence only indirectly affected by variations in the electrical portion of the circuit.

Fig. 5 shows the fundamental quartz oscillator circuit. C_1 represents the quartz mounted between two metal electrodes, L_1 is variously called a pick-up, sensitising, reaction or phasing coil, coupled to the plate coil L_2, the latter being tuned to the quartz frequency by the variable condenser C_2. C_3 is the usual radio-frequency by-pass condenser.

My theory of operation is as follows: Any slight shock to the electrical system (such as switching on) produces a damped oscillation in the tuned plate circuit L_2C_2. This induces a corresponding voltage in the grid circuit, but unless the grid circuit happens to be tuned to the plate circuit, merely assists in damping out the oscillations. If L_1C_1 (the quartz being considered

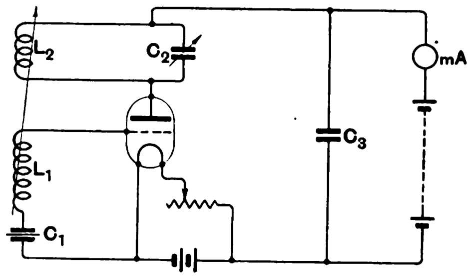


Fig. 5.

as an ordinary condenser) are in tune with the plate, we get ordinary self-oscillation. But if the voltage induced into the grid circuit is of nearly the same frequency as that of the quartz, then the voltage across the quartz actually increases, though the exciting voltage be dying away. This is because the energy supplied to the quartz is utilised by it in overcoming its damping, while the voltage generated only has to supply the losses in the high resistance of the valve filament-grid circuit. The fact that the voltage on the grid is building up in the correct phase enables more current to flow in the plate circuit, and in this manner the oscillations build up until the losses in

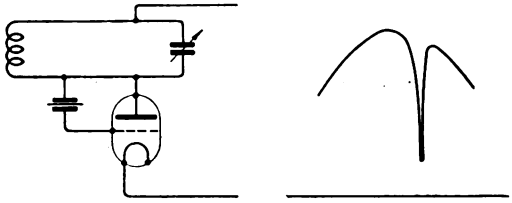


Fig. 6.

the grid circuit (whether due to radiation, resistance or damping of the crystal) exactly equal the power supplied.

It is a fortunate circumstance that the coil L_1 need not always have a separate existence, the necessary energy then being supplied either through the inductance of the wiring, or through the valve grid-anode capacity. In this case, outside disturbances can hardly enter into the grid circuit, as there is practically nothing for them to be coupled to. If the phasing coil be large, then it is possible to accelerate or retard the speed of vibration of the quartz by a very small amount.

The circuit just described may be improved in practice in many ways, chief of which is the permanent biasing of the grid through a radio-frequency choke. In some cases this R.F. choke appears to fulfil the functions of the phasing coil, without the disadvantage of causing frequency drift.

The circuits shown in Figs. 6, 7 and 8 have their special applications, and are all extremely steady.

A different class of circuit is shown in Fig. 9. It is a well-tried and popular transmitting circuit, across whose grid has been placed the mounted quartz. In this case (after retuning to allow for the added capacity) the quartz behaves like a self-adjusting condenser of a few $\mu\mu$F. Within a band of several thousand cycles around its response frequency, the quartz holds the transmitter perfectly steady. Outside these limits, the arrangement reverts to an ordinary tuned-grid transmitter.

There is one most important point about which information is at present entirely

lacking, and that is the criterion for breakdown of the quartz. Using the Fig. 5 circuit. I have cracked a 135-metre specimen with 700 plate volts. I have been informed that some thick specimens in the same circuit have cracked with only 150 volts on the plate. Doubtless similar experiences have led to the American rule-of-thumb, "Don't use more than 400 plate volts." However, Ridley* using the circuit of Fig. 9, with a 135-metre crystal and grid and plate circuits tuned to 45 metres, has successfully controlled a transmitter using 2,000 plate volts.

VII.—Accuracy.

As this term is frequently used in connection with quartz technique, care must be taken to examine the accuracies involved, in order not to cause confusion or needless expense by demanding unnecessarily accurate work.

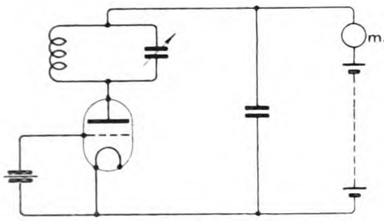


Fig. 7.

(a) *Accuracy of Measurement.*—As already stated the frequency of a quartz resonator may be measured to a fraction of one part in a million if required, on radio frequencies. Such a determination is extremely laborious, and for ordinary purposes within 100 cycles is good enough.

(β) *Accuracy of Setting-up, i.e.*, how closely a station may be established upon a given wavelength.—This again may be anything that is desired, but for broadcast work, within 300 cycles is all that is required. For the shorter wavelengths that are not yet so congested, one-tenth of 1 per cent of it is often ample.

(γ) *Accuracy of Operation*, which may be sub-divided into two main divisions :—

1. Temperature variations.—Although theoretically a crystal may be cut to have zero temperature co-efficient, a value of a few parts in a million per degree centigrade may be expected, accompanied by a possible temperature rise of 50°C. But when the cut is for maximum output, the frequency variation may reach several thousand cycles. Being a slow drift in

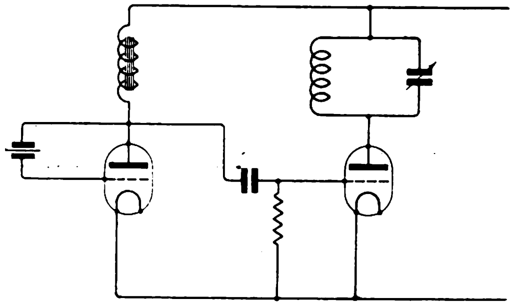


Fig. 8.

one direction, this may be allowed for very simply by allowing the crystal to attain working temperature before transmission begins.

2. Other causes.—These are chiefly changes in location or pressure of the electrodes, to be avoided if present by careful attention to the design, and residual coupling to the grid circuit consequent upon large changes in the main circuit.

VIII.—Quartz Testing.

It is not to be expected that immediate results will follow from a quartz crystal connected up among components selected at

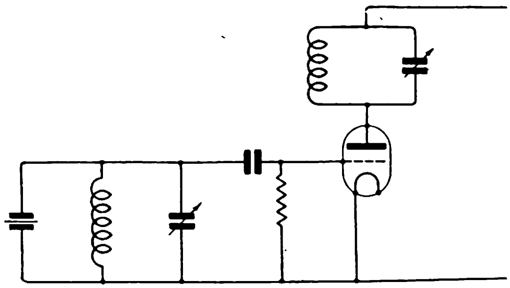


Fig. 9.

random, but until sufficient research has been carried out into the precise circuit conditions, it will often be necessary to go through a good deal of the procedure about to be given, merely to get the quartz to work at all, and thus to show the way for further improvements.

* *Modern Wireless*, December, 1926.

Connect up the circuit of Fig. 7, paying great attention to the components as specified.

Valve.—Receiving type of about 10,000 ohms impedance.

Coils.—Wound basket or Lorenz fashion, *not* spaced. The plate coil to give the expected wavelength with the condenser three-quarters in.

Condensers.—Plate of .001 or .0005$\mu\mu$F maximum. By-pass, .006 to .001$\mu\mu$F.

Electrodes.—Not too flat. The finish obtained by rubbing upon very fine emery paper on a board is often best.

Connect up as follows.—Bottom electrode to negative filament, top electrode to grid by means of 36 S.W.G. wire or finer. Place the quartz in position, and connect up the batteries.

Now vary the plate condenser very slowly from minimum to maximum, keeping careful watch upon the milliammeter needle. (Slowly means taking 30 seconds for the traverse.) Probably nothing will happen. Now connect as in Fig. 6, temporarily insulating the crystal holder from the bench, which is at earth potential. Bring the plate condenser slowly back from maximum to minimum. If nothing has happened, connect as in Fig. 5, using the smallest available coil (say 2 or 3 turns) very tightly coupled to the plate coil. Again bring the condenser from minimum to maximum very slowly, then reset the condenser to minimum, reverse the phasing coil, and repeat. Next try successively larger sizes of phasing coil, reversing them every time. Eventually a size will be reached such that the needle drops back immediately the coil is plugged in with the plate condenser at minimum. That is probably ordinary self-oscillation, which will occur just the same when paper or mica is substituted for the quartz. Measure the wavelength of the self-oscillation —as long as it is below that expected of the quartz all is well.

In the extreme case of self-oscillation occurring at about 5 per cent. lower wavelength than the quartz, the behaviour of the milliammeter needle will be thus: A moderate drop due to self-oscillation, a slow fall with a sudden jerk in it as the plate capacity is increased, a slow rise, perhaps a jerk upwards as self-oscillation almost ceases, but certainly another fall followed by a very sudden rise. The latter is due to the crystal.*

At whatever stage oscillations are observed, the coupling between the coils must immediately be loosened until they are very feeble, and the plate circuit retuned. Now try moving the top electrode relative to the quartz. Probably another position will be found, giving stronger oscillations. Again loosen the coupling and retune, and move the electrodes about until this avenue of improvement has been thoroughly explored. Now try a smaller phasing coil, tightly coupled. Once oscillations occur for practically the same plate condenser setting, but with different sizes of phasing coil, they are undoubtedly due to the quartz.

It may be that pressure on the quartz is wanted. With the holder described, it may be conveniently applied by means of weights resting upon a small box placed over the distance piece and knob of the top electrode.

Once a phasing coil can be used that does not cause self-oscillation wherever the plate condenser may be set, it is time to try other expedients, such as :—

1. Top electrodes of different areas, shapes and weights.
2. Different sizes of plate coil.
3. Other valves.
4. The effect of grid bias.
5. Different H.F. chokes to the grid bias.
6. Letting the quartz oscillate for several hours.

The golden rule to avoid cracking a crystal is: "When using a reaction coil, never allow the plate current to stay below one-third of normal for the briefest fraction of a second." Detune at once, and use looser coupling or a smaller reaction coil.

When the correct position of the quartz relative to the bottom electrode has been determined, it should be permanently located by screwing on the two corner pieces. Before making a new top electrode of correct size and weight, it is worth trying whether any output can be obtained with a minute air-gap between the quartz and the electrode. The increase in reliability may more than compensate for the reduced output.

* The quartz plate used for the demonstration had a frequency of 12,000,000 cycles.

With an amplifier following the crystal-controlled valve, the power radiated into the wiring of the grid connection is sometimes sufficient to permit the removal of the

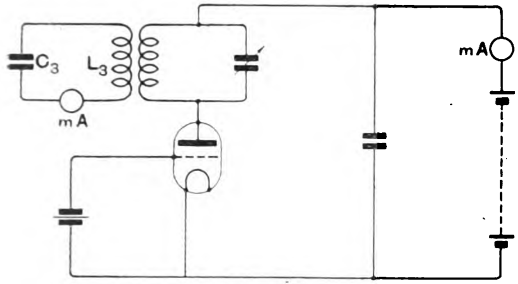


Fig. 10.

phasing coil, even though the latter be required for starting-up.

No great difficulty is found in getting the thicker quartz plates to oscillate. It is metres that call for some or all of the procedure just described. In any case, the time is well spent, for upon the adjustments so made once and for all will depend the technical excellence of the whole transmitter.

IX.—Elementary Applications.

The method of obtaining resonance points has already been mentioned.

Fig. 10 shows a testing arrangement due to Mr. Tingey. The quartz-controlled transmitter works on a fairly high wavelength, and the current in L_3C_3 is read on the measuring device *mA*. To use with batches of coils, a standard coil is placed for L_3, and a fairly large condenser C_3 is adjusted to give maximum current. C_3 is now left alone, and further coils can be adjusted to identical inductance by varying the turns to give maximum current in *mA*. Alternatively, if L_3 be large and kept fixed, small condensers may very rapidly be calibrated by placing them in parallel with C_3 and noting the reduction in capacity of C_3 necessary to bring the circuit into resonance again.

The circuits of Figs. 5 to 9 form extremely accurate frequency standards. The beat notes between the crystal fundamental and the receiver harmonics, or *vice versa*, occur over a wide range. Harmonics up to the tenth may usually be picked up at a distance of several feet, and higher harmonics with closer coupling. For example, a crystal of fundamental 823.6 kilocycles gives a direct calibration of the receiver upon such useful points as 45.53, 40.47, 36.42, 33.11 metres with ease and certainty, which far exceeds the accuracy of a heterodyne wavemeter. Upon important occasions, it takes just two minutes to confirm the receiver calibration, while a new receiver may be accurately calibrated in an hour.

X.—Advanced Applications.

The application of quartz frequency control to transmitting stations still offers a wide field. It has been proved by Goyder that crystal control permits the use of self-rectified A.C. on morse, or rectified smoothed A.C. on 45-metre telephony, yielding better signals than hitherto obtainable with a carefully and generously smoothed supply. The troubles known as rough notes, key thump and swinging of morse signals or mush and distortion of telephony, are readily cured.

The circuits already described form the nucleus of excellent transmitters for low powers of 5 to 8 watts, either by adding a key and/or microphone after the manner indicated in Fig. 11, or preferably by using one stage of amplification, however modest, so as to leave the crystal oscillating continuously and modulating the second valve.

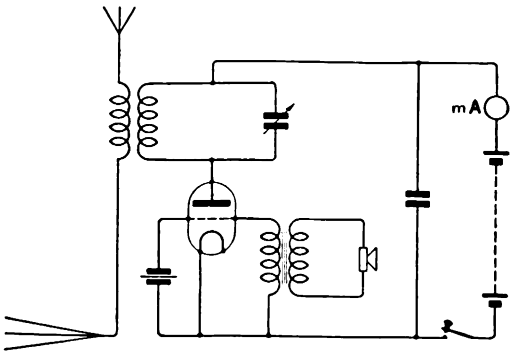


Fig. 11.

The great difficulty hitherto has been to apply the small power handled by the quartz-controlled valve to much larger transmitters. The old methods available were :—

1. The system of Fig. 9, which has not yet been fully investigated.
2. A system of H.F. amplification and frequency-doubling, to avoid the tremendous difficulties of constructing a straight H.F. amplifier on short waves.

A brilliant solution of the difficulty has been found by Mr. C. W. Goyder.* He uses a chain of self-oscillating valves, each handling about six times the power of the preceding one. In the ordinary way, such an arrangement would be hopelessly unstable, because the largest valve could hardly be prevented from feeding back energy to the grid coil of the preceding valve, and so on. But if the grid circuit of the first valve only contains mounted quartz, there is no grid coil to pick up the energy, and even if any energy should be induced, it would only affect the quartz frequency to a perfectly negligible extent. Consequently, the plate coil of the crystal-controlled valve can only contain oscillations at the one frequency dictated by the quartz. These oscillations are applied to the grid coil of the succeeding valve, which, though it be self-oscillating, will be held in exact synchronism over a band of several thousand cycles (or more than enough for practical purposes) and so on through succeeding valves. Should anything happen to one of the control valves, the main valve will continue to function uncontrolled. There is thus no increased risk of breakdown—all that would happen would be a falling off in quality to the standard existing before quartz control was applied.

DISCUSSION.

Mr. C. W. Goyder: It has been mentioned that when a quartz crystal is held near the coil of an oscillating receiver and the condenser is varied, clicks are heard at the resonant points of the crystal. I have found this effect very useful when grinding crystals. During any stage of the grinding the crystal can be held near the receiver and the approximate wavelength found without the trouble and time which would be required to clean the crystal thoroughly, and make it oscillate. This effect is due to the field around the receiver coil when it is oscillating. With the ordinary type of low loss spaced coil the field is strong enough quite a few inches away from the receiver. With concentrated windings, such as basket coils, it is not so easy to get a good click.

The method to follow is first to make the thick crystal oscillate and find the wavelength on the receiver, then hold the crystal near the receiver coil so that the resonance click can be found corresponding to this wavelength. The resonance may not be on exactly the same adjustment of the condenser as the oscillation. Now grind the crystal and every five minutes hold it near the receiver and find the resonance click, you will gradually get close to the wavelength you want. It is then advisable to clean the crystal thoroughly and measure up the surface at various points to see if the faces are parallel. It is important to clean the crystal well or you will get carborundum grains between the micrometer and crystal and then when the micrometer is screwed up they will scratch the surface of the crystal. I have ground crystals down from 130 metres to 90 and 100 to 60 quite successfully. Incidentally, the resonance click you get by holding any crystal near an oscillating receiver is a good test of the quality of the crystal. I can usually tell whether a crystal will oscillate just from this test.

I have been experimenting with crystals to see how long they will oscillate if left alone. They usually go for 8 hours or so and then stop. Sometimes they will start oscillating every time the valve is lit up, but sooner or later the valve is lit up and nothing happens. I have found the trouble to be that the crystal sticks to the bottom surface of the holder and has to be pushed before it will start again. This does not matter for ordinary work as it is quite easy to push the crystal occasionally, but for reliable work it is rather annoying. I find that a very thin piece of mica fixed on to each corner of the crystal prevents this sticking. It is worth doing this if the crystal is put in a holder or position where it is difficult to get at. The reason for this trouble seems to be that the air film under the crystal is gradually shoved out until it comes in direct contact with the metal. It is more noticeable when the surfaces are very true.

I noticed in an American paper that the Bureau of Standards have tried spluttering the faces of the crystal with a very thin layer of metal. A connection is made on to the faces with a wire at the corner of the crystal. This seems an ideal way of getting out of difficulties met with in crystal holders. The coating of the metal on the crystal has very little effect; it does lower the natural frequency a little, as might be expected.

The type of valve used with a crystal has quite a large effect. I have tried quite a number. The valve with a very low internal resistance certainly is not good. I have tried this type and could not get the crystal to oscillate. Valves with very high internal resistance work quite well but the power is low unless the H.T. is increased a lot. The correct value seems to be around 8,000 ohms. The mutual conductance seems to be quite an important factor. The higher it is the better. If it is not given with the valve you can get it by dividing the amplification factor by the resistance. Of a number of valves tested the one with the highest mutual conductance was the best.

The success of a set using the harmonic of the crystal and the harmonic of the amplifiers depends very largely on the strength of the harmonics. The valves should be worked in quite different ways, depending on whether you want even or odd harmonics. The condition for strong odd harmonics is that the positive and negative half cycles of the oscillation be distorted in the same manner. To get this condition with a valve the obvious way is to make the grid voltage swing the anode current above the saturation point for the positive half cycle and below zero plate current for the negative half. This gives almost equal distortion for both

* *E.W. & W.E.*, December, 1926. *T. & R. Bulletin*, December, 1926.

half cycles. To get this condition the filament should be turned down until saturation sets in with a low plate current and then the grid can be biased to work halfway between zero plate current and saturation.

Things are much easier in the case of even harmonics, as you get a strong even harmonic by distorting the positive and negative half cycle unequally. This can be done very simply by using a high negative bias on the grid. You get the strong even harmonic and at the same time the efficiency is much higher than you can get using an odd harmonic. So if you want to use the harmonic of a crystal for the 45-metre band it is better to get a 90 or 180-metre crystal rather than a 135.

The most noticeable effect of a crystal-controlled transmitter in the case of telephony is that the speech quality is better, and mush and ripple from the high tension supply is greatly reduced. Recently I tried an experiment with two separate stations, one in Ireland and the other in the North, using first a crystal-controlled set and then an ordinary self-excited circuit. In both cases the speech quality was much better and the H.T. ripple and mush was reduced when using the crystal. This effect is quite understandable as the crystal prevents the small changes of frequency which are bound to occur with any other kind of circuit, due to the modulation and variations in the H.T. voltage. The same effect makes it possible to use partially rectified A.C. and yet get a very good note.

I think Mr. Hinderlich has helped us greatly by his work on crystals. I shall never forget the trouble I had in getting my first crystal. It took me several weeks to find a natural quartz crystal, then I had to find someone who would cut the slice out, and then show them how to do it, and finally came the grinding part of the job, which took a long time. I am only too thankful that it did work in the end. Nowadays Mr. Hinderlich walks around with a boxful of crystals in his pocket. He has just sent me a beautiful crystal, working on its fundamental on 33 metres, it is only one-third of a millimetre thick. I think turning out a good crystal as thin as that is a work of art.

Mr. W. K. Alford: I should like to add my appreciation of the very interesting lecture we have heard. The great thing about the author's quartz control of transmitters and resonators is, I think, that it really affects us all to a greater extent than anybody realises. A great deal has been said about interference and although Mr. Hinderlich has not actually mentioned this point, I think—and I expect everybody is aware of it—the quartz oscillator supplies a wonderful solution for the elimination of broadcast difficulties, apart from our own experimental activities. I just mention this in passing, but it rather emphasises that it is a physical phenomenon which has apparently outlived radio as a science in the service of man, and it is very wonderful to think that it is now coming into its own as probably one of the greatest assets we can have in radio. I do not think there is anything to say on the actual technique of the subject of the lecture. Mr. Hinderlich has dealt fairly deeply with it and sufficiently deeply for those interested to start immediately on an investigation of their own. There is one great thing about these quartz crystals as oscillators or resonators and that is you have extremely little difficulty in deciding whether you have a good or a bad crystal. A man who has investigated the phenomena for the first time can quickly spot whether his crystal is going to oscillate or whether it is a "dud" crystal without having any deep technical information on the subject. The average person can get a start, as it were, in studying these piezo-electric effects. Mr. Goyder mentioned the fact of his buying quartz in some distant part and having to grind it. I remember I did the same thing, but I went a stage worse than Mr. Goyder and attempted to cut it, and I am very proud to say that I did cut it. I cut it into a strip roughly $\frac{1}{10}$ inch thick and it did not break but it took me roughly ten days. It was done with the aid of a hacksaw blade and 00 carborundum but the irony of it was that the crystal was a dud one after all! When you think of the work attached to the grinding of these crystals and what appears to be excessive price for a miserable piece of silica matter, perhaps having the wrong composition, we get some excuse for the price which is charged for these things.

Mr. G. G. Blake: There are one or two points on which I should like information from Mr. Hinderlich. Some time ago I saw in a paper that these crystals have been employed as couplings between stages of an amplifier, if Mr. Hinderlich is familiar with this application, I think a diagram showing how they can best be employed for this purpose would be useful. In 1922 or 1923, Langevin in France, using ultra-sonic sound waves employed a quartz crystal as transmitter and receiver. I do not know what circuit he used but in the transmitter he caused a crystal to oscillate and at the receiving end, when the sound waves arrived through water, I believe the sound waves caused the receiving crystal to oscillate and produce electrical oscillations which he then amplified. In 1925, Giebe and Scheibe in Germany made use of what they called a luminous piezo-electric effect, but although I looked it up in the library here this evening I was unable to find very much about it. There was a brief account in *Science Abstracts* for 1925 and 1926, and I saw that they used quartz rods 8 cm. long, and these when caused to oscillate, apparently glowed. It is stated that they were able to reproduce not only the fundamental frequency but in addition all the odd harmonics up to the 21st were observed and photographs were taken.

Mr. E. H. Robinson: I have been very interested in the whole lecture and I think it has been extremely useful to have all this matter put before us so clearly and concisely. I am afraid I have not anything to add by way of information as I have done practically nothing in quartz crystal work. It seems to me, however, that one enormous advantage of the quartz oscillator, especially the type in which you put the quartz in the grid circuit without any reaction coupling, or any apparent reaction coupling, is that it enables you to evade the reaction patents very nicely. I do not know if Mr. Hinderlich knows of any patent which covers the use of an oscillator in this way but it could be used commercially, I think.

Mr. E. J. Simmonds: Much attention seems to be given to the production of fundamental crystals

for short waves, but I think there are disadvantages, because below 50 metres they become very fragile, the percentage of crystals with good oscillating properties is small, whilst the power which such thin crystal handles is much reduced. There seems to be an idea that it is difficult to set up high frequency stages to multiply the original frequencies from long wave crystals. I do not think there are many difficulties, and perhaps an idea of what I do in my own station may be interesting. I am transmitting actually on 32.25 metres using an 129-metre crystal with intermediate frequency doubling stages, and the total amount of energy used in these two stages (the original crystal stage and frequency doubling stage) is 8 watts, and I find that I can with this arrangement efficiently control a 250-watt valve up to 200 watts input, that is the 250-watt valve is just under neutralised, and the output from the crystal amplifier is impressed on the grid circuit of the 250-watt valve.

I think that because this power stage is actually under-neutralised, most of the energy to swing the grid is supplied by the valve itself, and what actually happens is that the crystal amplifier with 5 watts in the frequency doubling stage is sufficient to trigger the grid of the power amplifier stage, and thus stabilise it.

I think that has some advantages over the self-oscillating systems using fundamental crystals, because I have observed in one or two stations using this arrangement of stabilisation all working on the fundamental, if the power valves are working somewhere near the full dissipation, the anodes are bound to heat up to a considerable extent and get a change of inter-electrode capacity and a consequent frequency change in the relative circuits.

I know that the one or two stations using this method have to adjust their circuits as the valves heat up until they come to stability. On the system I use, I do not have that difficulty because the last stage is already neutralised. An interesting system was described by Hund in a paper read before the I.R.E. in November, 1925. He describes a system of chain amplifiers with, I think, 20 to 25 watts to control 200 watts, and so on in that ratio, but the point was, that the grids of all the amplifiers had a large negative bias, so that until the crystal started oscillating, there would be no plate feed current to the valves at all, and there would be no tendency to self oscillation, the whole thing being controlled by the original crystal. Mr. Hinderlich mentioned somewhere that a quartz plate in the thickness of which there was a difference of 25 per cent. in the different parts was quite satisfactory. This seems contradictory, because Hund also mentions the application of quartz crystals ground with a minute step, the idea being to produce two radio frequencies, closely related, from the same crystal, and thus obtain a resultant audio frequency, which might have a large number of applications. I find it is preferable to use crystals with good self-oscillating properties, and strongly depreciate the use of crystals which require any form of magnetic reaction to make them work. I find it is better to use a crystal of comparatively long wavelength, as it is easier to get good specimens, and thus dispense with the reaction coil, or any form of choke in the grid circuit. In the low power tests on 45m., I used a crystal which required magnetic reaction to maintain oscillation, and every time I started up I got a fresh frequency. Many crystals used with reaction will often stabilise the frequency at a number of points, and it is troublesome to have to retune every time.

There is also the question of calibration from a fixed crystal standard of long wavelength. I use an N.P.L. calibrated crystal with a frequency of 530,600 cycles approximately. The crystal is permanently fixed up in an oscillating circuit, and it is quite simple and easy to read the harmonics right down to the 25th, which provide a large number of plot points on the short wavelengths.

Mr. A. E. Underdown: I am particularly interested in this lecture as I have been engaged in experiments of this nature myself for some months.

In the first place, I should like to ask Mr. Hinderlich whether he is absolutely certain about the 150 and 105 factors, and if he can give me any information as to how a crystal responding to a wavelength of 150 metres per mm. of thickness differs from one of 105 metres per mm.?

Also, the band of control, Mr. Hinderlich says, is something of the order of a few kilocycles, but I should like to know what wavelength he had in mind as a band of a few kilocycles is not very large when dealing with very high frequencies. For a 300-metre crystal, the oscillating circuit would be tuned to a frequency in the neighbourhood of one million cycles per second, and presumably if that circuit is adjusted to more than two or three kilocycles above one million, *i.e.*, the resonant frequency of the crystal, it will fail to control. I should like to know the maximum percentage of frequency difference between the tuned circuit and crystal with which it is possible to work. At 300 metres I have been able to work with the oscillatory circuit tuned to 285 metres, *i.e.*, 50 kilocycles away from the fundamental frequency of the crystal.

With regard to permanent holders, I have a circuit arrangement with which I seem to be able to make practically any crystal oscillate and its reliability of control has made it possible to design a simple and robust crystal holder with a comparatively large air-gap. Scrap pieces of quartz have been ground down roughly irrespective of their surfaces, and they have oscillated quite readily without any trouble.

Most quartz crystal enthusiasts seem to be following up the American methods of crystal control, but I have found that, without the aid of reaction, control is generally more or less uncertain I have departed from the usual lines of working and with my arrangement it is possible to control with an air-gap of over 2 mm. between the crystal and electrodes; the usual air-gap employed is about 0.1 mm. to 0.2 mm., unless the crystal is actually in contact with the electrodes.

I have had very little experience with the disc type of resonator which makes use of the transverse vibrations—my experiments having been confined to the rectangular type employing the longitudinal vibrations. You will probably raise the question of the control of short waves. Well, it is possible to make a tiny piece of quartz about 2 mm. square and 1.5 mm. thick oscillate on a wavelength of

about 250 metres. A small piece may be cut or even chipped off an odd bit of quartz and ground down to the required size, when it will be almost sure to function.

Another point is in connection with broadcasting. A week or so ago I read a statement to the effect that the B.B.C. did not intend to make use of crystal control because, in their opinion, it was rather unreliable and not so accurate as some people were led to believe. I should like to hear what Mr. Hinderlich has to say on this point, because I have had extraordinarily good results and in some of my measurements the high tension, low tension and even the gap between the electrodes were varied appreciably without affecting the frequency more than 20 to 30 cycles in a million. This order of constancy, however, could not be expected where the air-gap is exceedingly small.

Mr. A. D. Gay: There are one or two points I should like to endorse, particularly with regard to the vagaries of crystals when they are used with a reaction coil. I also have found that you are never quite sure whether you are going to start up on the same wavelength you were last using. But it is quite a definite control, and by using that form of control you can get a number of steps all of which seem to give good outputs; there is no doubt about the controlling effect, because if you use a valve rectified supply with practically no smoothing you get pure D.C., and there is a great advantage in that. Mr. Hinderlich mentioned the condenser across the plate coil; did he say it should be about two-thirds?

Mr. Hinderlich: Yes.

Mr. Gay: I do not quite agree there, because I have tested a large number of crystals and have found that if you do not go above 5 degrees of the condenser certain crystals will oscillate, whereas if you put in a smaller coil and put in more condenser the crystals will not oscillate. I found on several occasions that it was necessary to keep the capacity at a minimum, and I should like to know whether, in that circuit in which Mr. Hinderlich showed two valves, the choke is an audio-frequency choke; the author drew it as an iron-core choke, and I wondered whether that was a mistake. With regard to Mr. Underdown's remarks about making any odd pieces of quartz oscillate; I have not made them oscillate except with a reaction coil, and then I have found that the effect of those pieces of quartz is more an absorption effect than an oscillating effect, because I have actually found no current that one could measure by ordinary means passing through the crystal. When a crystal is used and is properly oscillating you get quite an appreciable current, but it is very minute when you are using it in an absorption circuit.

Mr. S. Ward: I think the remarks of the lecturer to-night have been of very considerable interest to everyone, and especially to me. I have carried out a certain amount of investigation into quartz crystals, and there are one or two points which I should like to mention. Mr. Hinderlich did not say very much about the question of gap. I have made several experiments on that, and I find that most crystals work best with a gap. That has been my experience in testing a number of them, and the method I have used for getting and measuring the gap is to fit up an ordinary 2 in. micrometer held in a vertical position by means of a clamp, and to fit a little disc platform on to the lower anvil and a similar one on to the top portion, one of them being insulated, of course. By that means one is able to measure the thickness of the crystal and also to measure the gap, and most of the crystals which I have tried certainly work best with a gap of anything up to 0.005 in. The output is increased up to a certain point, possibly about 0.003 in. in most crystals I have tested. Beyond that it begins to fall off, and generally at round about 0.005 in. or 0.006 in. it ceases to function. In most cases I have found it necessary to use a reaction coil to get the crystal to start. Sometimes, as Mr. Hinderlich has mentioned, it would carry on after starting with a coil. I like the fundamental circuit he has given, because it seems to have one advantage, in that the absence of a grid-leak really means that you have a very high grid-leak, and, as soon as the valve oscillates, its anode current goes down very considerably, which is a great advantage. When the valve is not oscillating, and you are using an ordinary dull emitter valve, the anode current is considerable—not that that matters very much unless you happen to be using fairly high plate voltage. Another point Mr. Hinderlich mentioned was that the polishing of the crystal would probably increase output. I thought the same thing myself, and so I took one crystal, which was rectangular in shape—its length being about twice its breadth, and its thickness about 1 mm. or so, perfectly plain and parallel—cut it in halves and polished one half, but could not find any difference between the two halves. That is the only one I have treated in that way, and I have found no difference whatever; both halves apparently worked quite well. The question of a chain of amplifiers in controlling the transmitter seems to be rather an important one, because a lot of people have tried making up these high frequency amplifiers, and the great difficulty which one would expect to come up against is the question of the feed back, as mentioned by several speakers.

Neutralising is one way of doing it, but it always seems to me much more satisfactory to use the frequency-doubling method, which, if properly arranged, can be used entirely without any neutralisation. If the harmonics exist in each circuit and you pick each one out independently, making each circuit a distorting circuit, it is not necessary to neutralise each stage. One starts with a large, thick crystal, and goes down in wavelength each time, doubling the frequency at each stage. That seems to be a much more satisfactory method of working than to amplify from the fundamental with neutralisation at each stage. There is one other point I should like to mention, and that is the use of Rochelle salt in place of quartz. I do not know how many people have tried it, but it is a thoroughly unsatisfactory substance to use. It looks very nice; it has good resonating properties, it is very cheap, and it is very easy to work, but it is thoroughly unsatisfactory as an oscillator and it is very difficult to prevent the stuff changing owing to its hygroscopic properties. You cannot keep it constant for any length of time; it is very erratic. The production of crystals is a matter of some difficulty, but they can be obtained,

and I do not recommend anybody to try to use Rochelle salt in place of quartz.

Captain Robinson : I only wanted to say that I quite agree with Mr. Goyder as regards the relationship between capacity and inductance in crystal controlled circuits. I have found that the three or four crystals I have had have all oscillated best when the capacity was small and the inductance large. I believe the author disagrees with that. It may just happen that the few crystals I have experimented with work better that way.

Mr. G. G. Blake : Possibly these crystals may suffer from fatigue and I should very much like to know if you, sir, or anybody who has been working with them, has come across this drawback. It seems to me rather an important thing for us to know whether in use these crystals do suffer from fatigue.

Mr. Underdown : I have found that to be the case.

Mr. Robinson : I find that some will work one day and will not work the next and so on.

Mr. Hinderlich, replying to the discussion, said: I have tried to cover the whole ground in this paper by giving references to published papers that cover parts, and so I find that I have not actually stated many necessary details. For example, Dye's paper, which runs into 21 pages, covers many of the points raised by various speakers, such as Giebe's "luminous" quartz, and the effect of air-gaps between 3 and 0.2 mm. Clayton and Hund both discuss the two wavelength/thickness ratios, and Ridley and Goyder give details of their systems of control, which have only been in use at a few stations, so it is yet too early to make valid comparisons.

Several speakers have criticised my reaction coil method. I consider it invaluable in the early stages, as without it you often find you have a transparent object, alleged to be oscillating quartz, which flatly refuses to work. Use reaction, and you can find the correct tuning, and the way to improve results. But a transmitter with a reaction coil I admit to be a very poor affair. For one thing, you get the trouble of several fundamentals, and then the frequency is apt to shift or wander. A crystal that requires reaction is really only fit for a wavelength standard where a small inaccuracy is permissible.

With regard to thin crystals, few people have tried the 33 and 23-metre ones. When further research work has been done, I feel sure that crystals of similar properties will occur, whatever the thickness, and that our present difficulties in finding enough good thin ones will disappear.

One would expect a station to creep a bit owing to temperature effects, but I will ask Mr. Goyder to answer that question.

Mr. Goyder : I have had some trouble due to a gradual drift of frequency but I do not think it is due to the valve or the method in use. I have always found it was caused by a poor inductance. If the wire is too small in cross section or if the di-electric on which it is wound is poor, it gradually heats up and so the wire moves due to expansion, or just because the di-electric gets soft. It makes quite a large frequency change on the short waves. I used an inductance wound on a wooden frame, boiled in wax for 90 metres and 45 metres, when I tried it on 32 metres the wood warmed so much that the wax melted! At present I am using an ebonite frame and I have no trouble. A poor high frequency choke can cause the same trouble.

Mr. Hinderlich, continuing, said: All the precepts I have enjoined this evening were more of an indication than positive injunctions. I find my way works, and that a lot of others do not, at first. The reason I suggested using a large condenser with a small coil was partly that when testing you want plenty of room at the bottom, to see when the self-oscillation is going to end, and partly because it does not follow that a large coil is going to give better results. Occasionally it spoils them. Anything that will make the crystal oscillate easier should be used.

I am very interested in Mr. Ward's observation that a fairly critical value of air-gap around 0.003 in. (0.08 mm.) gives the best results in an oscillator. I had not noticed anything of the sort, and it is not easy to try, but I will have a go at it.

As regards tuning-fork versus quartz, I could talk for hours, but it is a case of knowing the accuracy required. If you ask for absolute accuracy, you will never get it, but you can get whatever accuracy you require in practice. I am not aware of any attempt to measure the results obtained with quartz. The inherent accuracy satisfies most people.

I do not see how you can avoid using a micrometer when grinding—it will be wanted to keep the faces nearly parallel. I am surprised at Mr. Goyder's difficulty. I put mine under the warm water tap and dry off with an old handkerchief. If you should have a grain of abrasive, you can hear it being crushed by the micrometer.

I brought my specimen with the 25 per cent. variation in thickness along to demonstrate my point that the state of the surfaces does not make a tremendous amount of difference. The oscillating power must exist in the rough specimen.

At an intermediate stage of the grinding, I much prefer to have the crystal rather wedge-shape Then any supplementary wavelengths are immediately obvious. With a crystal having two wavelengths, you might, with fairly good workmanship, get such values as 39.9 and 40.1, and never spot the trouble for a long while. Excessive reaction promptly brings out any supplementary wavelengths, as noticed by Mr. Simmonds. Curiously enough, I have known beautifully polished specimens that failed to work until one surface was roughened, though usually a good surface improves the results.

It is impossible to give much information about Patents, as those taken out months ago are now being published, but if Mr. Robinson will look up the patents in the names of Eccles, Goyder, Hinderlich, Hoyt Taylor and Standard Telephones, he will find something.

The idea of coating the quartz itself with metal is most attractive, and only the practical difficulties in the way of applying a thin coating have prevented my trying it.

I do not think that quartz suffers from fatigue, which is easily simulated by the sticking electrode trouble.

Mr. Bevan Swift: We are deeply indebted to Mr. Hinderlich for coming here and telling us all about crystals; whether it is the broadcast listeners wanting crystals for reception or of the transmitter wanting to tie his wavelength down, Mr. Hinderlich can advise us. I remember that some time ago he came down to our local Society and told us all about crystals for ordinary receivers, and we thoroughly enjoyed that lecture. Now he comes to us to-night with a more advanced subject and tells us how to tie our wavelengths down to one spot so that they will not jump off it. I do not know anything about crystal-controlled transmitter working myself. I have not used it, but I know I can tell a crystal-controlled station directly I hear it, and it is quite a treat to listen to it. I think that great praise is due to Mr. Hinderlich, Mr. Goyder, and others who have made a feature of crystal control. I am sure it is the coming thing for the amateur transmitter, as well as the commercial station.

Amateur Long-Distance Work.

By Hugh N. Ryan (5BV).

INTEREST, or at any rate the interest of a large section of the transmitter community, centres at present on the results of the week of low-power tests organised by the R.S.G.B. and, more particularly, on the regular low-power work which many stations are now carrying out, doubtless under the stimulus of the organised tests in November. At the time of writing, the detailed results of these tests are not yet available. It appears that, as so often happens, the participants' enthusiasm for the tests was not equalled by their subsequent zeal in reporting their results. However, one knows the general trend of these results. First and foremost, the tests proved definitely that, given care and organisation, 5 watts is a thoroughly useful power for reliable communication over distances of several thousand miles, but it is doubtful whether this can yet be said of the same power used in the ordinary course of work without special organisation. This desirable result, however, should follow in a very short time now that more stations are devoting themselves to the problems involved in the use of low power. The tests have shown those who are compelled by circumstances to use low power, and who have perhaps not yet met with success, that they are not up against an impossible task.

Before the tests, many Irish Free State stations had been very successful with low power, and the promise thus shown was evidently fulfilled in the tests themselves, as the "GW" stations did very well indeed.

Judging from the general trend of all reports received this month, conditions would appear to have favoured unusually good reception of transatlantic stations in the early evening here (this applies especially to reception in the North) and very frequent and good reception of Japanese stations, especially in Ireland. Most stations in the South of England report a period of poor conditions, while no Welsh station reports anything at all.

Space only permits of a brief reference to the work of individual stations. 6NF has worked 3CYB (Spanish W. Africa) with 5 watts in daylight. It is interesting to note that, for his higher-power work, 6NF is directly crystal-controlling his main power valve, with 1,000 volts on the plate, which voltage he is soon increasing. 6LJ is out of active operation for some time but his extensive work on weather condition effects has reached an advanced stage, and should soon be available.

6UV has been carrying out a detailed investigation of the "skipped distance" question, mostly with the very efficient co-operation of SMWF (Stockholm).

6KO (Scotland) has been working with a hand-generator and a large receiving valve, and besides effecting two-way working with several transatlantic stations has been heard on at least two occasions in Australia.

5NJ remains the leading station in Northern Ireland, and with 75 watts is in constant touch with most of the world. Of the other "GI" stations, 6YW, 6MU, 5WD, and 5MO have all worked the U.S. with 5 watts or less. (The call 5MO, famous as that of a pioneer long range station in the north, is now re-allotted in Ireland.)

The most active stations in Southern Ireland are 11B, 18B, and 19B, all of whom have worked America with 10 watts or less.

[Reports on low-power long-distance work are welcomed.—Ed.].

Some Notes on Design Details of a High-Power Radio Telegraphic Transmitter Using Thermionic Valves.

Paper read by Dr. R. V. HANSFORD, and Mr. H. FAULKNER, B.Sc., before the Wireless Section, I.E.E., on 1st December, 1926.

Abstract.

THE paper deals with various specific points in the design of a high power transmitter, more especially that at Rugby, being largely supplementary to Mr. E. H. Shaughnessy's paper on the Rugby Station (abstracted in *E.W. & W.E.*, May, 1926).

The paper is divided into six sections :—

I. Consideration of the most suitable type of aerial circuit from the point of view of the elimination of undesirable harmonic emissions.

II. The design of the electrical proportions of the aerial circuit.

III. The inductance coils for the aerial circuit.

IV. Some notes on valve circuit design.

V. Keying and shape of signals.

VI. Recent results at Rugby.

Part I.

Type of coupled aerial circuit from point of view of elimination of undesirable harmonics.

This is discussed by comparisons of the alternative circuits shown in Fig. 1.* As regards coupling to the valve, it is shown (in an appendix) that the use of a condenser rather than an inductance as the "anode tap" (*i.e.*, types *B*, *D*, and *E*) gives a reduction of harmonics in the aerial in the ratio of m^2 for the m^{th} harmonic, that is *B* and *D* are m^2 better than *A* and *C* respectively. The same applies to coupling to the aerial, *i.e.*, *E* is m^2 better than *D* and m^4 better than *C*. It is pointed out, however, that when designing a circuit for an aerial not yet erected and of constants not accurately known, it would be expensive to provide a range of condenser values for a type *E* circuit to cover all the variations required in the experimental period of tuning and adjustment.

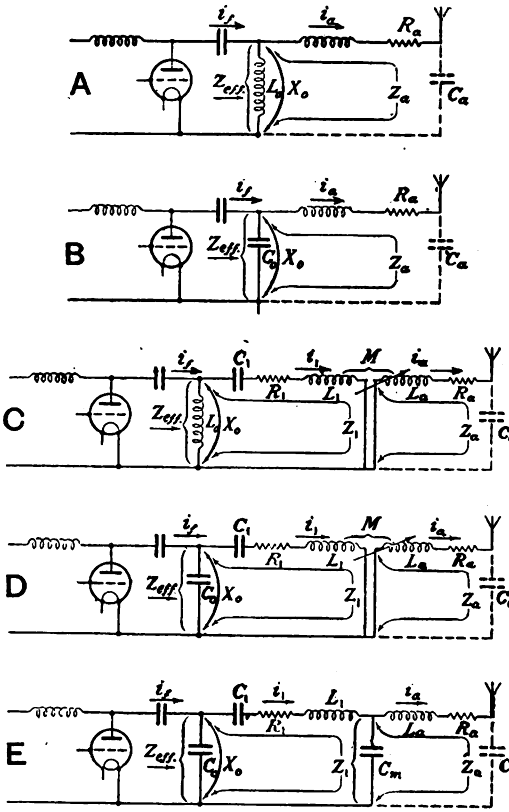


Fig. 1 *Types of output circuit.*

The *D* type circuit has therefore been used, and transition from *D* to *E* can be made comparatively easily and inexpensively should it become necessary.

* The author's original figure numbers are used throughout this abstract.

An expression of the "improvement factor" as regards harmonic elimination is given as—

$$\frac{\pi \delta_a}{\delta_1 \delta_a + \pi^2 k^2} \quad .. \quad .. \quad (2)$$

or

$$\frac{\pi}{\delta_1 + (\pi^2 k^2)\delta_a} \quad .. \quad .. \quad (3)$$

Where δ_1 is intermediate circuit decrement, δ_a is aerial decrement and k the co-efficient of coupling. These expressions must be multiplied by a power of m depending on the nature of the couplings.

of the value of the inductance, and it is desirable for reasons of voltage and cost that the value of inductance chosen should be as low as is consistent with design considerations. The mean value of inductance chosen for the intermediate circuit at Rugby was therefore 500μH. (See Fig. 3.)

From a curve given showing the relations between efficiency (abscissa) and improvement factor, co-efficient of coupling, and intermediate circuit current and power, it is shown that for an improvement factor of 40 and efficiency of 95 per cent., k would

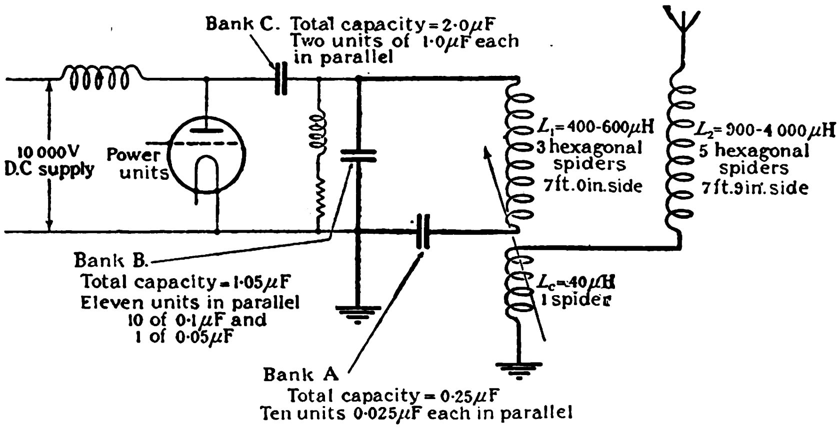


Fig. 3. *Coupled aerial circuit.*

Part II.

Design of the Electrical Proportions of the Coupled Aerial Circuit.

Taking a D type circuit as a basis, it is shown that the efficiency n of coupled circuits

$$= \frac{\pi^2 k^2}{\delta_1 \delta_a + \pi^2 k^2} \quad .. \quad .. \quad (8)$$

From (2) and (8) it is seen that the efficiency and improvement factor are both independent of the ratio of inductance to capacity in the intermediate circuit except in so far as this ratio may affect δ_1. Therefore, since with a given value of k both expressions are dependent on δ_1, the problem from both points of view is to design an intermediate circuit of minimum decrement consistent with reasonable cost.

Within the inductance limits imposed by practical considerations the decrement of a well-designed coil for the intermediate circuit can be assumed to be practically independent

require values of from 0.0088 to 0.0107. The range of mutual inductance called for is therefore from 5 to 40μH, which was provided by the use of a moving coil of 40μH coupled directly to the intermediate circuit inductance, as in Fig. 3.

It was next necessary to fix the "anode tap" condenser (Bank B, Fig. 3). From examination of the probable extreme conditions, it is shown that 0.37 to 1.03μF would be required. This was provided by 10 banks each of 0.1μF, and one unit of 0.05μF. The value of Bank A could then be calculated from the known limits of frequency.

The high frequency condensers were all tested at the manufacturer's works in accordance with a detailed specification.

An inductance coil in series with a resistance so proportioned as to make the circuit non-oscillatory, is connected across the anode tap condenser to ensure that practically the whole of the D.C. voltage is taken by the blocking condenser, Bank C.

Part III.

Inductance Design for High Power Radio Transmitter.

The three main points to be decided are (1) size and type of conductor, (2) the method of supporting the conductor, (3) the method of providing the necessary variation of inductance.

The design of the Rugby inductance was based on experience gained at Northolt, which led to the manufacture by the P.O. Engineering Department of its first large stranded-wire inductance. This gave interesting information regarding the necessity for efficient insulation of the stranding.

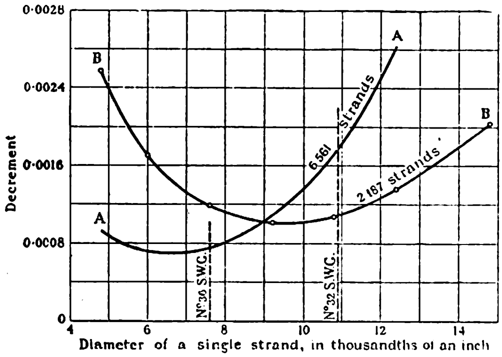


Fig. 6. *Variation of calculated decrement of a large inductance with type of cable used — four spiders, eight turns per spider; external diameter of outside turn = 15 ft. 9 in.*

Curves are given showing the effect of stranding, and comparison between measured and calculated results at Northolt, these being in good agreement, having regard to dielectric and eddy losses not allowed for in theoretical calculation.

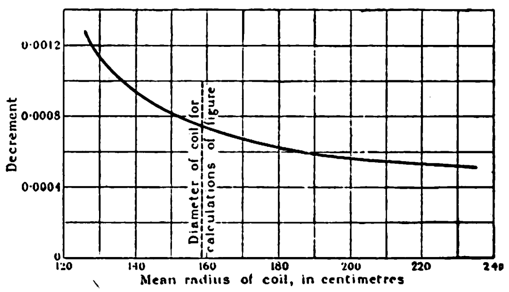


Fig. 7. *Variation of calculated decrement of a large inductance with diameter of inductance—four spiders; inductance approximately constant at 2,920H.*

It was decided to base the design of the Rugby inductances on the results of similar calculations. Inquiry elicited the fact that 6,561 strands was probably the limit of the manufacturing plant in this country, while spiders of 16 ft. diameter were as large as could be conveniently handled.

Fig. 6 shows calculated comparisons between 6,561 and 2,187 strands, while Fig. 7 shows the variation in calculated decrement of a cable of 6,561 strands with variation of external diameter.

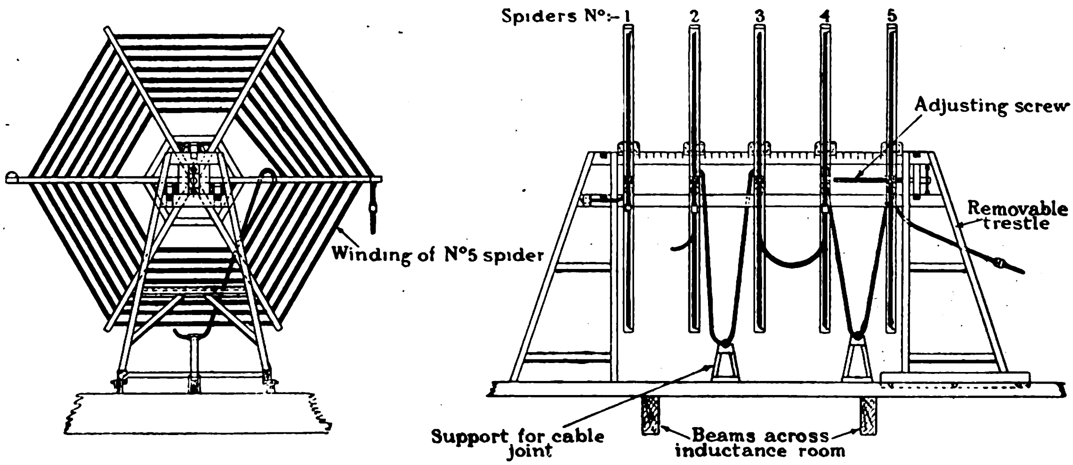


Fig. 9. *General arrangement of aerial tuning inductance.*

Another curve also shows the comparison between calculated and measured decrements for the Rugby coil. Allowing for losses in the framework and surroundings, the agreement is considered satisfactory.

The general arrangement of the aerial tuning inductance is shown in Fig. 9. The spider is of American whitewood, which has proved itself very suitable for the construction of such frameworks.

Considerations of the possibility of voltage breakdown gave a minimum spacing of 10 inches between spiders, which were actually arranged for a minimum of 1 foot.

Part IV.

Notes on Valve Circuit Design.

Experiments were also carried out at Northolt with valves of the type to be used at Rugby, and gave considerable preliminary information about the working conditions. It was found that two different conditions of working could be employed, where the input and output were practically identical although the conditions of operation were widely different. The cases are compared in the table below and in Fig. 11.

TABLE I.

	Case I.	Case II.
D.C. voltage	10,000V	10,000V
Direct current	1.39A	1.41A
Grid A.C. voltage (R.M.S.	2,000V	880V
Grid bias	1,330V	164V
Mean grid current ...	0.19A	0.082A
Oscillating current ...	28A	28.1A
High-frequency output (R=13.3 ohms) ...	10.4kW	10.5kW
Efficiency	74.8%	74.5%

In Case I the anode current has a peaky shape which is assumed in the example considered to be a half sine wave from which a third harmonic of one-third the amplitude is subtracted. In Case II it is of double-lumped shape, assumed to be a half sine wave to which the third harmonic has been added. From analysis on these assumptions it is shown that the efficiencies of the two systems are as shown in the following table.

TABLE II.

	V_0=10,000V	V_0=7,000V
Case I.	66%	57%
Case II. ...	64%	61%

In Case I the peak value of anode current is nearly five times the mean current: in Case II it is only three times. As Case II demands a considerably less maximum from the filament, it is more economical from the point of view of valve life.

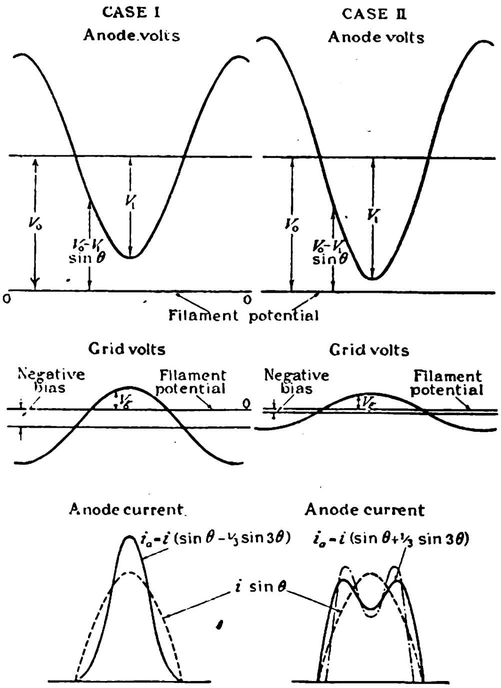


Fig. 11. *Showing alternative methods of operating the valves.*

Another substantial advantage is that greater outputs and higher efficiencies are obtainable when working at the lower anode voltages. It has been experienced that the behaviour of valves when tested in a low-power test set may be very different from that which obtains when used in a high-power transmitter. Current discharges, many times the maximum filament emission, can and do

take place through the valve and may leave it quite unaltered as regards hardness and characteristics. In a low-power set the discharge causes an immediate drop in voltage which allows the valve to regain its equilibrium. In a high-power set the voltage drop on overload is not so marked and the valve has not the same opportunity of quick recovery. In these circumstances the discharge often causes the vacuum to be broken down.

The phenomenon may occur with hard valves (previously tested up to 12,000 or 15,000V) in the region of 7,000 volts D.C., and becomes more frequent as the voltage is increased. It is therefore concluded that in the present state of valve development high power sets should be designed to work on comparatively low voltages of the order of 7,000V.

Part V.

Keying and Shape of Signals.

The arrangement of Keying is shown in Fig. 15, reproduced from Mr. Shaughnessy's original paper. It is explained that three keys have been provided at the points marked *a*, *b*, and *c* and that the combination of a grid-leak resistance with a grid bias generator for the final stage of power amplification enables a selective discrimination to be made between the mean grid bias used for signals and that used for "space," the conductivity of the valve increasing the decrement of the coupled aerial circuit during the space, and so improving the shape of the signals. The oscillogram of Fig. 16 shows the shape of the signals at 40 w.p.m., using the three keys and with 800 amperes in the aerial. The difference in decrement

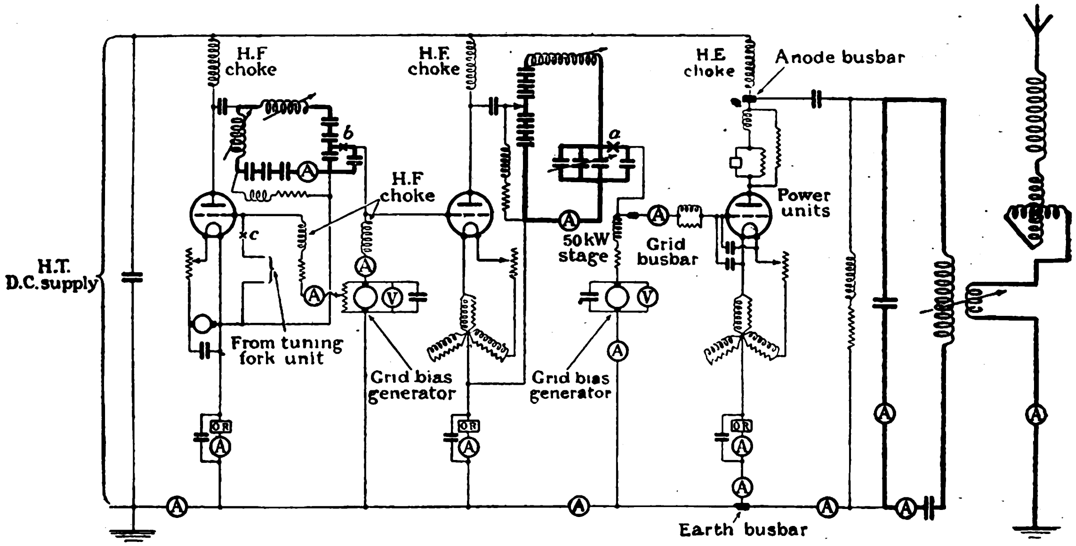


Fig. 15. *Skeleton diagram of transmitting circuits.*

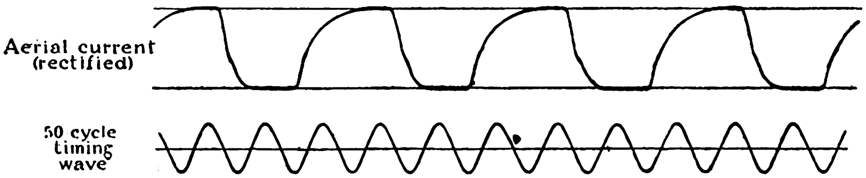


Fig. 16. *Keying 800A in aerial at 40 words per minute using three keys.*

on rise and fall is very marked, being for rise 0.0057 and for fall 0.011.

The necessity of taking a load through the valves with "key up" is then considered, and illustrated by several oscillograms showing the effect on the shaping of signals under different conditions.

It has been proved to be practicable to key the circuit by the use of one only of the three keys provided, *i.e.*, either at position "*a*" or at position "*c*" of Fig. 15, and oscillograms are also given of the signal shapes under these conditions.

Part VI.

Recent Results at Rugby.

Since Mr. Shaughnessy's paper was read, the complete aerial supported by 12 masts has been brought into use for the telegraph set. The aerials on the north and south sides of the building are led in separately and joined in parallel by means of a stranded wire cable supported by insulators from the roof inside the building. At 16,000 cycles the aerial has effective capacity 45,000$\mu\mu$F and effective inductance 358μH. The use of the combined aerial has enabled the normal working current to be increased from 550 to 740 amperes, the following table showing a schedule of readings for normal working conditions.

TABLE III.

Schedule of Readings for Normal Running Conditions.

	VT26	VT30
Type of valve in use ...	VT26	VT30
Number of power units in use ...	3	2
Total number of valves in power units	54	30
Aerial current (A)	740	700
Aerial power (A) at 0.61 ohm (kW)	335	300
Total D.C. input to transmitter :—		
Voltage (V)	6,300	6,500
Current (A)	73	70.5
Power (kW)	4,608	4,608
Filament power (kW)	48	41
Efficiency of transmitter % :—		
Excluding filaments ...	72.5	65
Including filaments ...	66	60
Voltage on antenna (V) ...	166,000	157,000

Valve type VT26 is rated at 10 and type VT30 at 20kW respectively.

The aerial resistance with masts insulated and earthed is shown in Fig. 25.

Tests were carried out with masts insulated and earthed on alternate days, the results of measurements made in America being shown below.

Measurement at	Masts Insulated	Masts Earthed
Houlton-Maine	578 $\mu V/m$	541 $\mu V/m$
Washington ...	131 $\mu V/m$	120 $\mu V/m$

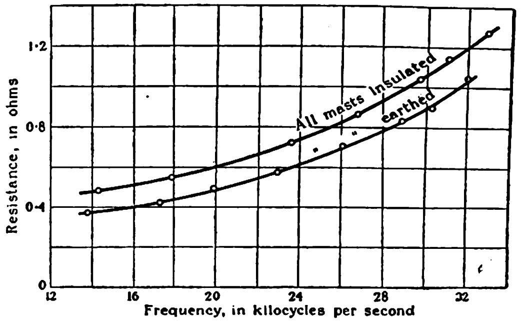


Fig. 25. *Aerial resistance curves for complete aerial using 12 masts.*

APPENDIX.

An appendix shows the detailed development of certain of the mathematical expressions used in Part I.

DISCUSSION.

The discussion was opened by **Mr. L. B. Turner,** who recorded his admiration of the great work which the Post Office had done and to the author's large share of responsibility in the work. He then discussed the oscillograms of signal shaping, referring to similar work of his own on the shaping of signals at the receiver. As regards the coupling circuit for minimising harmonics, the comparison of capacitative and inductive coupling was of great importance. He suggested the Post Office should proceed with the further condenser coupling to the aerial. This would permit greater coupling to the aerial and improvement in the delay action on signals.

Mr. G. Shearing also expressed great admiration of the work described. The addition of a rejector circuit with the Type A coupling gave good freedom from harmonics. He asked for information as to the relative cost of 6561/36 and 2187/32 stranded wires for comparison of economy and technical advantages; also as to the behaviour of the white-wood frameworks under damp conditions from fresh and salt water.

Mr. B. S. Gossling said the design of valves was now a matter of economics. A valuable contribution was given in the paper in the alternative conditions of operating giving the same efficiency. As regards the running cost and valve life, he agreed that reduction of emission was very important. He also discussed at some length the discharge effect mentioned in Part IV of the paper.

Mr. A. C. Warren also discussed this discharge, which he said had been attributed to a Schottky effect, although he expressed doubts of this. Possibly it was an effect of gas, perhaps from the copper anode. The problem was to prevent gas. If the effect was due to this it would occur at very definite voltages which depended on the geometry of the valve.

Col. A. G. Lee discussed the effect of coupled circuits and their phase relationships on the shape of signals, illustrating his remarks by the use of the familiar two-pendulum model.

Mr. Faulkner briefly replied to several of the points raised in the discussion ; and on the motion of the Chairman (**Prof. C. L. Fortescue**) a cordial vote of thanks was accorded to the authors.

Abstracts and References.

Compiled by the Radio Research Board and reproduced by arrangement with the Department of Scientific and Industrial Research.

PROPAGATION OF WAVES.

MAGNETIC STORMS AND WIRELESS COMMUNICATION. —(*Nature*, 118, 6th November, 1926, p. 662.)

A letter from Sir Joseph Larmor referring to the report recently that communication with Canada, by the new beam system of rays of short wave-length, had been completely blocked by a magnetic storm. He questions this, since the fluctuations of magnetic force are but slight, and the rays might be expected to arrive by an altered path. He suggests a deeper and more fundamental cause, namely, that the magnetic storm itself is due to an incursion of free electrons into the upper atmosphere, in such numbers as to upset all the ray-paths and twist them out of regularity. The only alternative, he says, seems to be oscillation of the magnetic field so rapid as to be comparable with the time of transit of the ray, which is very unlikely.

ZUR BERECHNUNG DES ROTATIONSSYMMETRISCHEN STRAHLUNGSFELDES (Calculation of the radiation field of rotational symmetry).—F. Kiebitz. (*Annalen der Physik*, 80, 7, pp. 728-740.)

An integration of Maxwell's equations for the case of a radiating field, free from loss, of rotational symmetry, which leads to the following results :—

1. In every radiating field of rotational symmetry, that is free from loss, the direction of the field at any point in space can be calculated algebraically.
2. The electric field is propagated along the rays with the velocity of light.
3. The field strength in each ray is inversely proportional to the distance from the axis of symmetry.
4. If there is a large conducting sphere, with the source of radiation on its surface, the rays run in circular form from the transmitter as pole to the opposite pole.
5. The field lines in this case are circles, standing upright on the sphere's surface, with their centres lying on the axis of symmetry.

DIE AUSBREITUNG DER ELEKTRISCHEN WELLEN, INSBESONDERE DIE GERICHTETE AUSBREITUNG (The propagation of electrical waves, particularly directional propagation.) — F. Kiebitz. (*Elektrische Nachrichten-Technik*, 3, 10, pp. 376-382, October, 1926.)

An address to a Wiesbaden electrical meeting last June, when the author dealt with two of his contributions to our knowledge of wave propagation, namely, his mathematical description of the propagation of waves around the globe, which is summarised in the preceding abstract, and his morse sign method of directional transmission (*Jahrb. drahtl. Tel.*, 15, p. 290, 1920), which he believes could yield valuable information on directional telegraphy with the co-operation of broadcast listeners.

IONIZATION IN THE UPPER ATMOSPHERE.—S. Chapman. (*Royal Meteorological Society Journal*, 52, 219, pp. 225-236.)

A lecture delivered before the Royal Meteorological Society. The paper is divided into six sections dealing with the subject from the following aspects : Reflection of wireless waves ; comparison of wireless and magnetic results ; the cause of the general ionisation of the upper atmosphere ; the mode of ionisation of the air ; ionisation associated with auroræ, in high latitudes ; the auroral ionisation and spectrum.

A bibliography of the subject is appended.

GENERAL ELECTRIC SHORT WAVE TEST RESULTS. —M. Prescott. (*Q.S.T.*, 10, 11, November, 1926, pp. 9-13.)

The results are given of a series of investigations on radio wave propagation conducted by the General Electric Company with the co-operation of about 500 amateurs. The tests were carried out on transmissions varying from 20,000 to 2,750 kC. The observations included day and night audibility, antenna comparison and fading. The results for audibility and antenna comparison are shown by means of curves. With regard to fading, this was recorded during both day and night transmissions on each of the frequencies under observation. Its occurrence was found to be a function of the frequency, becoming more troublesome as the frequency increased. The observers all found fading more pronounced at night than by day and that for both day and night an increase in the distance from the transmitter showed a lessening of the fading effect.

SHORT WAVE TESTS.—(*Scientific American*, November, 1926, p. 385.)

The Naval Radio Research Laboratory at Anacostia, D.C., is co-operating with 40 stations scattered over a territory of 7,000 miles in making tests on the 25.6-metre wavelength. So far it has been found that these signals are not audible in daylight within a 500-mile radius of the transmitter, but that the intensity is good in the zone between 700 and 1,200 miles, and that from 2,000 to 3,000 miles the waves seemed more uncertain than within the 2,000-mile region.

Horizontal Wave Experiments at 2AER.—J. Hollywood. (*Q.S.T.*, 10, 11, pp. 32-33, November, 1926.)

The general problem of wave propagation is briefly examined, illustrations being shown of the "pebble in the pond" theory, the radiant ray theory, and the "line of force" theory.

The tentative conclusion is drawn that radio energy is transmitted in the form of lines of force which are reflected from the ionised layer of the atmosphere in straight lines.

The experiments show that for local and long distance work, the transmitting and receiving stations should both use the same type of transmission and reception, either vertical or horizontal; while for semi-local and medium distance work, the signals should be transmitted vertically and received horizontally—this method being also best for ultra short-wave work.

ATMOSPHERICS.

Les Perturbations Orageuses du Champ Electrique et leur Propagation à Grande Distance.—P. Lejay. (*L'Onde Electrique*, 5, 58, pp. 493-499, October, 1926.)

The introduction and first two of five chapters of a communication delivered before the S.A.T.S.F., 14th April, 1926 (thesis for the doctorate). The paper is summarised as follows:—

Introduction: Brief outline of what we know about storms; general character of the earth's electric field at the Pic du Midi Observatory; conditions under which the experiments described were made; relative constancy of the field on a mountain.

Chap. I.: Recall of the mathematical expression for the field produced by a rectilinear discharge compared to a doublet. Applications to the discharge of clouds: the variation of the static field should be felt at a great distance; the effects produced on an antenna and a frame can be very different; the radiogoniometry of atmospherics is only possible at a great distance.

Chap. II.: The variations of the static field during storms have been measured with a radium potential collector joined up either to an electrostatic voltmeter, or in the case of distant storms, to a new amplifying electrometer, the principle and method of employment of which are described in detail.

Chap. III.: Analysis of some ten storms, varying in distance from 1 to 100 kilometres, shows that the variations of the static field reach 300 volts per metre at 30 km. from the lightning and some tenths of a volt at 100 km. It is proved, on the one hand, that the flashes coincide with the occurrence of atmospherics in the receiver, but on the other hand, there are numerous sudden and violent variations of the field without any luminous manifestation.

Chap. IV.: The circuit arrangement ordinarily employed to analyse atmospherics by the cathode oscillograph deforms the disturbances: these last a very short time and assume very complex forms.

Chap. V.: Meteorological data do not conflict with the preceding results, but to a certain extent confirm them. It is not right to assert in general that atmospherics have no range—this depends on the violence of the discharge that has given rise to the disturbance and can be considerable.

Abstracts of Papers on the Meteorological Relations of Atmospherics.—R. A. Watson Watt. (*Journal of the Meteorological Society*, 52, 218, pp. 199-208.)

A bibliography of the relations between meteorological phenomena and the intensity of atmospherics compiled for a committee appointed to consider whether observations on atmospherics might be of service in weather forecasting. From the summary of conclusions by different observers it is seen that, apart from overwhelming unanimity in favour of the correlation between the occurrence of actual thunder or lightning and atmospherics, and moderate agreement in the correlation with convective processes in the absence of reported thunder, the evidence is contradictory. Reasons assigned for this are:—

1. The range of reception for atmospherics reaching probably the length of the earth's semicircumference, comparison between received atmospherics and local weather is to a certain extent like comparing the weather of a parish with the electrical phenomena of a hemisphere.

2. It is still impossible to find a scale and a classification for the intensity and character of atmospherics which shall be generally acceptable, unambiguous, and capable of assessment by the average observer.

Mr. Watson Watt writes in conclusion, however, that the evidence that the atmospheric was well, if rashly, named is accumulating rapidly, and the summaries of the most recent work show that the location of "cold fronts" by radio telegraphic observations on atmospherics is an established possibility.

Progressive Lightning.—C. V. Boys. (*Nature*, 20th November, 1926, pp. 749-750.)

An article referring to the papers recently published by Dr. Simpson and Dr. Dorsey on the start and progress of a lightning flash. Mention is made of a paper by Dr. Hoffert that it is thought these authors have overlooked. This paper shows that a lightning flash is very often multiple: two, three, or many more flashes succeeding one another very rapidly along exactly the same path. It also shows, with the help of photographs, that a flash within a cloud, terminating (or starting ?) at a point from which the main flash started, preceded this by a very evident interval, and that this region remained luminous until the third main flash had occurred. Prof. Boys further relates an observation of his that may also have some bearing on the conclusions of the two authors. On one occasion when watching a storm he noticed that for every flash seen in the rain cloud and below, there were simultaneously one or more very slender flashes from the cloud upwards, many times as long as the lightning below, reaching perhaps halfway towards the stars of the Great Bear (which were in their lowest position)—at one moment there were seven of these flashes going into the clear sky.

Prof. Boys also describes apparatus he has made for obtaining experimental evidence of the progress of the lightning flash.

LIGHTNING DISCHARGES.—T. Gilbert. (*Electrical Review*, 26th November, 1926, pp. 870-871.)

The phenomenon of the lightning discharge is explained with particular reference to the protection of radio aerials and apparatus.

DIE GRÖSSE DES LUFTELEKTRISCHEN KONVEKTIONSSTROMES (The value of the atmospheric electric convection current).—W. Schmidt. (*Physik Zeitschr.*, 27, 14, pp. 472-473.)

A new calculation of the atmospheric electric convection current showing that the density of the upwards directed current is less than $\cdot 87.10^{-9}$ stat. units/cm² sec. and therefore not greater than the eight-hundredth part of the supposed mean conduction current (about 7.10^{-7}).

PROPERTIES OF CIRCUITS.

ÜBER KIPPSCHWINGUNGEN, INBESONDERE BEI ELEKTRONENRÖHREN (Concerning "tilting" oscillations, particularly with valves).—E. Friedländer. (*Archiv. für Elektrotechnik*, 16, 4, pp. 273-279, July, 1926; 17, 1, pp. 1-16, September, 1926; 17, 2, pp.103-142, October, 1926.)

The production of "tilting" (*i.e.*, in unstable equilibrium) oscillations, periodic changes of charge of a single store of energy, is shown to occur in a series of systems containing no actual oscillatory circuit. These oscillations are characterised by the cyclic sudden changing of an unstable position of equilibrium. The frequency is essentially determined by the time constants and applied tension and not by the natural frequency of any part of the system. This in general only comes into evidence when with the tilting of the charged store of energy there is no discharge path available. Of the known means for generating undamped oscillations the valve has not yet been remarked as a producer of tilting oscillations, and in this article a simple valve oscillator, with transformer grid and anode circuit coupling, is investigated for the tilting phenomena. The oscillograms obtained are in agreement with the forms of oscillation found theoretically. It is also shown that every amplifier is in a position to execute tilting oscillations and that only the fact that involuntary back-couplings occur to disturb their development can explain the exclusion of undesired oscillation phenomena in many cases.

ON "RELAXATION-OSCILLATIONS."—B. van der Pol, Jun. (*Philosophical Magazine*, 2, 11, pp. 978-992, November, 1926.)

A consideration of the equation

$$\ddot{v}-\epsilon(1-v^2)\dot{v}+v=0$$

with the supplementary condition $\epsilon \ll 1$, and an investigation of the sequence of events when $\epsilon \gg 1$. No approximate analytical solution could be obtained with this latter condition, but it is shown how a graphical solution may be easily found. The equation for the quasi-aperiodic case, which differs considerably from the normal approximately sinusoidal solution, is shown to have again a purely periodic solution, the time period of which is expressed by the time of relaxation of the system—hence the suggestion of the term "relaxation-oscillation" for this phenomenon.

ERZWUNGENE SCHWINGUNGEN IN ANGEFACHTEN SYSTEMEN (Forced oscillations in excited systems).—F. Ollendorff. (*Archiv für Elektrotechnik*, 16, 4, pp. 280-288.)

An investigation of the properties of forced oscillations in coupled systems for the particular case of the oscillating audion and a method of integrating the fundamental equation is outlined that is applicable to all coupled systems.

LOAD CARRYING CAPACITY OF AMPLIFIERS.—F. Willis and L. Melhuish. (*Bell System Technical Journal*, 5, 4, October, 1926, pp. 573-592.)

A paper describing the adaptation of the cathode ray oscillograph to the determination of the overload point of vacuum tube amplifiers. Using the input voltage to produce a horizontal deflection, and the output voltage or current to produce a vertical deflection, the amplifier performance is readily determined by noting the resulting figure on the fluorescent screen. So long as the figure is virtually a straight line or an obviously undistorted ellipse, the amplifier output is free from harmonics, but as soon as overloading begins, the oscillogram shows either a sharp bend at either or both extremities of the line or apparent distortion of the ellipse. The method has the advantage of being quick.

GIBT ES EINEN UNTERSCHIED ZWISCHEN STOSSERREGUNG UND AUSSIEBUNG VON OBERSCHWINGUNGEN BEIM RUHENDEN FREQUENZWANDLER? (Is there any difference between impact-excitation and the filtering out of harmonics with the static frequency changer?) —R. Kümmich. (*Zeitschr. für Tech. Physik*, 17, 7, pp. 337-345.)

The principal phenomena in frequency multiplication by static transformers can be regarded from two points of view: one that it is a case of the filtering out of harmonics (also selection of the higher harmonic named), the other that it is a question of impact excitation. It is shown here that the physical phenomenon is capable of only one interpretation and can be looked at from either aspect, which only appear to be contradictory.

SUPERSONIC TRANSFORMERS. — N. McLachlan. (*Wireless World*, 10th November, 1926, pp. 631-634; 17th November, 1926, pp. 680-684; 24th November, 1926, pp. 715-718.)

A paper in four parts dealing respectively with the design and performance of iron-cored types, the measurement of transformer magnification curves and valve coefficients, the measurement of primary inductance, effective primary capacity and optimum wavelength, and the application of these transformers to superheterodyne circuits.

GENERAL FORMULÆ FOR TWO SYNTONISED COUPLED CIRCUITS.—R. Wilmotte. (*Philosophical Magazine*, November, 1926, 2, 11, pp. 1,098-1,108.)

TRANSMISSION.

MODULATION UND ÜBERTRAGUNGSGÜTE IN DER HOCHFREQUENZTECHNIK (Modulation and quality of the transmission in high-frequency technics).—F. Trautwein. (*Zeitschr. für Techn. Physik*, 17, 7, pp. 345-352.)

Discussion of the correctness of the frequency and amplitudes in broadcast transmission—which it is for the most part possible to obtain with present day technique. All that seems to be lacking is a technically useful method of modulating one side band, which the author suggests supplying by combining two oscillations, modulated after the two-side band, whose high and low frequency parts are 90° out of phase.

L'EMISSION À FAIBLE PUISSANCE.—R. Desgrouas. (*L'Onde Electrique*, September, 1926, 5, 57, pp. 489-490.)

A brief note enumerating the merits of the "symmetrical circuit arrangement" for short-wave communication.

A SHIELDED CRYSTAL-CONTROLLED UNIT.—J. Clayton. (*Q.S.T.*, November, 1926, 10, 11, pp. 22-25.)

Detailed description of a compact completely shielded unit which may be used either as a good low power outfit or as a "feeder" for a larger, and unshielded, amplifier.

RECEPTION.

WAVE PROPAGATION IN OVERHEAD WIRES WITH GROUND RETURN.—J. Carson. (*Bell System Technical Journal*, 5, 4, October, 1926, pp. 539-554.)

A solution of the problem, required for the theory and design of the wave antenna, is given here for the case where the actual earth is replaced by a plane homogeneous semi-infinite solid, the complete solution not being possible, owing to the inequalities in the earth's surface and its lack of conductive homogeneity.

NOTES ON WIRELESS MATTERS.—L. B. Turner. (*Electrician*, 8th October, 1926, pp. 412-420; 12th November, 1926, pp. 556-557.)

Continuation of the discussion of the detector problem begun in the *Electrician* of 10th September. A letter from "R.L.H.," in the issue of 12th November, p. 564, questions Mr. Turner's assumption that the form of the signal is sinusoidal.

NOTE SUR UN NOUVEAU MONTAGE NEUTRODYNE. —F. Dufrenoy. (*L'Onde Electrique*, 5, 57, September, 1926, pp. 487-489.)

Diagrams of two new neutrodyne circuit arrangements are shown utilising to the full the difference of potential in the oscillating circuit.

RADIO INTERFERENCE.—R. Ashbrook and R. Wight. (*Electrical World*, 23rd October, 1926, pp. 851-853.)

An article dealing with "man-made" interference as distinct from atmospherics. The causes of such interference are discussed and experiments in locating it described.

STATIONS: DESIGN AND OPERATION.

BROADCASTING IN SWEDEN.—(*Electrician*, 12th November, 1926, p. 560.)

Details are given of the new 30-45kW station that is being erected at Motala, on Lake Vättern, about 200 km. south-west of Stockholm. The rectifying system consists of 8 water-cooled tubes each rated at 10kW at 10,000V anode potential. The drive oscillator has 1 water-cooled tube with 10,000V on the anode, derived from 2 air-cooled rectifier tubes, while the amplifier system comprises 4 water-cooled tubes in parallel, of the same rating as the rectifier tubes. The filament takes 50 amps at 20V. The wavelength, which it is hoped will be definitely allocated for this station, is 1,350 metres. It is expected that relay stations will be set up at Boras, Halmstadt, Uddevalle, and Upsala.

CANADA — TRANSMITTING STATIONS. — (*Electrical Review*, 12th November, 1926, p. 798.)

A short paragraph under "Radio Notes," stating that there are now 543 transmitting stations in Canada, of which 67 are broadcasting stations, 356 are amateur and experimental, 67 are code stations, and 46 are operated on the coasts and great lakes for the benefit of shipping. All broadcasting and other wireless in the Dominion is under the direction of the Dominion Government Department of Marine and Fisheries.

RADIO SIGNALLING SYSTEM FOR THE NEW YORK POLICE DEPARTMENT.—S. Anderson. (*Bell System Technical Journal*, 5, 4, October, 1926, pp. 529-538.)

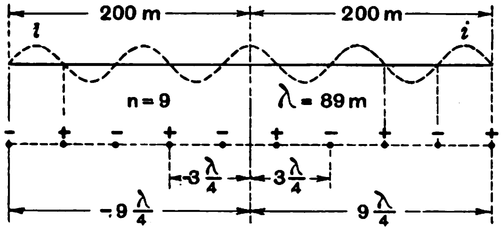
By means of the system described it is possible, through the addition of a comparatively simple attachment to a standard radio telephone transmitter, to modulate the carrier with an audio-frequency tone in such a manner as to provide for calling individually, simultaneously, or in a number of designated groups, any one of several hundred radio receiving stations. At the receiving stations apparatus is provided giving a visible or audible signal to the operator that a message is about to be broadcast to which he should listen.

DIRECTIONAL WIRELESS.

STRAHLUNGSUNTERSUCHUNGEN AN HORIZONTALEN SENDEDRÄHTEN, DIE IN EINER HÖHEREN HARMONISCHEN ERREGT SIND (Investigation of radiation from horizontal transmitting wires excited in a high harmonic).—G. Grimsen. (*Elektrische Nachrichten-Technik*, 10, 3, pp. 361-376.)

Exciting a horizontal conductor, placed close to the earth's surface, in its ninth harmonic, produces marked directivity in the radiation from it. To calculate the distant effect characteristic of this horizontal arrangement, its total radiation is replaced by the sum of the radiations from a row of perpendicular dipoles, oscillating with the same frequency and amplitude and alternately of opposite phase, as represented in the figure below.

This substitution is permissible when the distribution of the field lines radiating from these vertical dipoles is the same at the earth's surface as that due to the horizontal antenna. This is the case if the conductivity of the ground plays the same part in the range of these short waves as with long waves, *i.e.*, the lines of electric force close to the transmitter are perpendicular to the earth's surface and horizontal components are absent. On this assumption, the radiation diagram calculated for the ninth harmonic of a conductor 380 m. long ($\lambda = 85$ m.) shows marked directivity in the direction of the axis, and places where the radiation is nil on either side of it.



This calculated radiation diagram was tested experimentally by taking field measurements with a movable receiver (thermo-element and galvanometer) in different directions around the transmitter, when the results were found to be in good agreement with the theoretical figure. Confirmation of the theoretical propagation diagram was also obtained by means of Kiebitz' inverse morse sign method (*Jahrb. drahtl. Tel.* 15, p. 299, 1920), divergences between calculated and observed values being only remarked at places where disturbance of the propagating medium was likely owing to the presence of transmission lines or antenna structures.

IMPERIAL WIRELESS "BEAM" COMMUNICATION. (*Electrical Review*, 29th October, 1926, pp. 709-712; 5th November, 1926, pp. 749-751.)

The first public telegraph service operated on the short-wave beam system was opened on 21st October. An account is given here of the English stations concerned, at Bodmin and Bridgwater, for transmitting and receiving respectively, the corresponding stations in Canada being at Drummondville and Yamachiche.

The inauguration of the Canadian beam service is also discussed in *E.W. & W.E.* for December, pp. 715-716, and the Bodmin and Bridgwater stations are described in the *Wireless World* of 3rd and 24th November respectively.

THE FLYING LOOP.—O. Wright. (*Q.S.T.*, 10, 11, November, 1926, pp. 36-40.)

The results are given of tests with a frame aerial installed on a De Haviland airplane.

VALVE DESIGN AND THERMIONICS.

REACTIVATING VACUUM TUBES. (*Scientific American*, September, 1926, p. 224.)

A short paragraph quoting from a Technical News Bulletin of the National Bureau of Standards.

The method given for restoring filaments to full activity is to disconnect the "B" batteries from the receiver and burn the filaments above normal brilliancy for half an hour.

THERMIONIC EMISSION OF THE METALS TUNGSTEN, MOLYBDENUM, THORIUM, ZIRCON AND HAFNIUM. C. Zwikker. (*Proc. Royal Acad. Amsterdam*, 29, 6, pp. 792-802.)

Discussion concerning the value of A in the emission formula

$$i = AT^2\ 10^{-\,\bar{T}}\ Amp./cm.^2$$

It is shown that for every pure metal surface examined A could be represented by 60.2. Discrepancies found in the case of zircon and hafnium are attributed to their being covered with an oxide layer up to the melting point.

THE EFFECT OF A HYDROGEN ATMOSPHERE ON THE VELOCITY DISTRIBUTION AMONG THERMIONIC ELECTRONS.—C. del Rosario. (*Physical Review*, 28, 4, October, 1926, pp. 769-780.)

The thermionic current from a tungsten or platinum filament to a coaxial cylindrical electrode was measured for different retarding potentials, first in vacuum and then in hydrogen, keeping the temperature of the filament constant. The distribution of velocities among the electrons in vacuum and in hydrogen was found to follow Maxwell's law and, contrary to the experience of former observers, the temperature calculated from the Maxwellian distribution was found to be the same for the case of a vacuum as for that where hydrogen was present. The maintenance of thermal equilibrium between the electrons and the filament in hydrogen suggests the elastic nature of the collisions between the electrons and the hydrogen molecules.

MEASUREMENTS AND STANDARDS.

ESTABLISHMENT OF RADIO STANDARDS OF FREQUENCY BY THE USE OF A HARMONIC AMPLIFIER.—C. Jolliffe and G. Hazen. (*Scientific Paper No.* 530 *of the Bureau of Standards.*)

The method consists essentially of the production of harmonics of the fundamental frequency of an alternating current by means of the non-linear characteristics of valves, the selection of any desired harmonic by means of tuned circuits, and its amplification to sufficient power to operate a standard frequency meter (wavemeter). Any harmonic of the source may be selected, and thus from a known audio-frequency source a frequency meter may be standardised throughout its entire range.

DIE GRAPHISCHE DIMENSIONIERUNG VON ELEKTRISCHEN SCHWINGUNGSKREISEN (Finding the dimensions of electrical oscillatory circuits graphically).—E. Asch. (*Zeitschr. für Techn. Physik*, 17, 7, pp. 330-332.)

A graphical method is described of finding the natural frequency of capacities and inductances joined together in parallel.

DISCUSSION ON PORTABLE RECEIVING SETS FOR MEASURING FIELD STRENGTHS AT BROADCASTING FREQUENCIES, BY A. JENSEN.—G. Gillett. (*Proc. Inst. Radio Engineers*, 14, 5, October, 1926, pp. 699-705.)

A paper showing how these sets are being used in the field in actual field strength measuring work and their great value for research work.

A NEW METHOD OF OBTAINING FREQUENCY STABILISATION OF A TRANSMITTER BY MEANS OF AN OSCILLATING QUARTZ CRYSTAL.—C. Goyder. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 717-724.)

Description of a method of employing the oscillating quartz crystal to obtain a constant frequency at a transmitter, which is said to have decided advantages from the point of view of simplicity, flexibility, efficiency and reliability, over the method of pure high-frequency amplification at present in general use.

THE ABSOLUTE MEASUREMENT OF RESISTANCE AT RADIO FREQUENCIES. R. Wilmotte. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 725-729.)

SUBSIDIARY EQUIPMENT AND MATERIALS.

MAGNETIC PERMEABILITY OF IRON IN HIGH FREQUENCY ALTERNATING FIELDS.—G. Wait. (*Physical Review*, 28, 4, October, 1926, p. 848.)

Abstract of paper presented at the Oakland meeting of the American Physical Society last June. Wwedensky and Theodortschik have found the magnetic permeability of iron in alternating fields to be abnormally large in certain frequency bands, and nearly normal in other regions. The wavelengths corresponding to these bands were approximately 88 metres and 100 metres. The general appearance of the phenomena suggested the existence of resonators corresponding to these frequencies. The effect has also been observed by Kralovec. The writer has repeated the experiments and finds the permeability of the samples used much more constant than would appear from the measurements of these investigators. Two experimental methods were used: one consisted in the measurement of the inductance of a coil by a resonance method, the inductance being measured with the sample inside the coil and with it out; and the second method employed a heterodyne arrangement of two high-frequency valve circuits and one of audio frequency

LE FONCTIONNEMENT DES AMPÈREMÈTRES THERMIQUES EN HAUTE FREQUENCE.—J. Granier. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 45-48.)

LES TRANSFORMATEURS. — J. Vivie. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 11-23.)

An article dealing principally with the mathematics of the transformer.

A SENSITIVE VACUUM TUBE RELAY.—W. Hoffman and F. Schnell. (*Q.S.T.*, 10, 11, November, 1926, pp. 20-21.)

Description of a relay developed from a circuit appearing in a recent issue of the *Wireless World*. A diagram is given of the modified circuit and a photograph showing the arrangement of the apparatus.

FURTHER NOTES ON THE LAWS OF VARIABLE AIR CONDENSERS.—W. Griffiths. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 743-755.)

GENERAL PHYSICAL ARTICLES.

METHODEN UND ERGEBNISSE DER KLANGFORSCHUNG (Methods and results of sound research).—F. Trendelenburg. (*Zeitschr. für Hochfrequenz*, 28, 2, pp. 54-64; 28, 3, pp. 84-91.)

After considering the theoretical bases for the investigation of sound and examining the different methods, the results are discussed in so far as they affect the questions of sound transference and reproduction.

A SIMPLE EXPOSITION OF ELECTRO-MAGNETIC RELATIONS. — H. Biggs. (*Philosophical Magazine*, 2, 11, November, 1926, pp. 1052-1056.)

THE SCATTERING OF CATHODE RAYS.—B. Schonland. (*Proc. Roy. Soc.*, 113, A763, November, 1926, pp. 87-106.)

MISCELLANEOUS.

ÜBER DIE RÜCKWIRKUNG DES MENSCHLICHEN KÖRPERS AUF SENDER UND EMPFÄNGER BEI KURZEN WELLEN (The reaction of the human body on transmitter and receiver with short waves).—N. Skritzky and W. Lermontoff. (*Zeitschrift für Hochfrequenz.*, 28, 3, pp. 82-83, September, 1926.)

During the authors' work at the Leningrad experimental electro-technical laboratory where various transmitters and receivers for wavelengths of 1-4 metres were set up and tested, observations

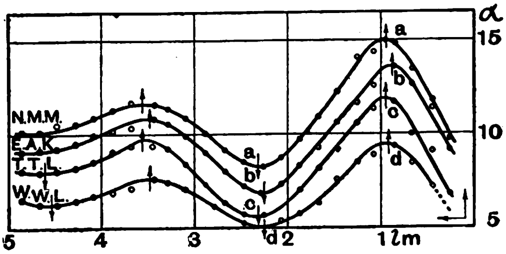


Fig. 3

were made throwing light on the question of the effect of a person's presence near the apparatus, a description of which is given here.

Two series of observations were made:—

In the first series a person moved perpendicularly to the line joining receiver and transmitter along a straight line passing through the centre of the receiving frame. The readings on a galvanometer

in the receiving circuit corresponding to his different distances from the receiver are shown in curve *a* below (where the abscissæ are distances and the ordinates the readings) characterised by a succession of maxima and minima.

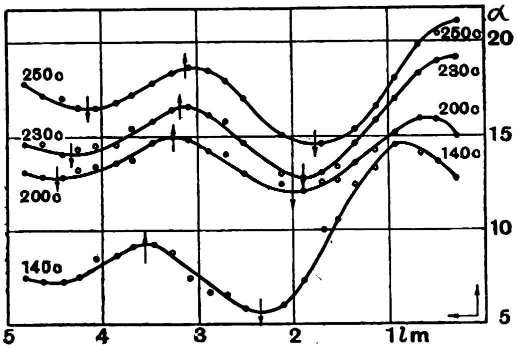


Fig. 4.

The curves *b, c, d,* with their ordinates displaced for the sake of clearness, represent the phenomena for three other people. All the curves show the same character—only the position of the maxima and minima varying slightly in each case.

In the second series of observations, instead of a person, a wooden stick carrying a copper wire was moved along the same path. The stick alone did not affect the galvanometer, but with wires of different lengths the following curves were obtained.

The series of maxima and minima obtained in the two sets of observations are seen to be very similar. Now a copper rod in the electro-magnetic field of a progressing wave absorbs a part of its energy and radiates it again in the form of forced oscillations of the transmitter frequency, the interference curves (Fig. 4) thus representing the resultant effect of two electro-magnetic fields acting simultaneously on the receiver, and the great similarity between the two series of curves permits the conclusion to be drawn that the effect of electro-magnetic fields in the human body is similar to that in a straight oscillator, *i.e.*, the body absorbs radiation energy and sends it out again in forced oscillations of the transmitter frequency.

The effect of different persons is somewhat different, but the question whether the method can be used conversely for giving information on the living organism must to-day be left undecided the authors say.

La Determination des Differences de Longitude par Télégraphie sans Fil.—L. de la Forge. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 38-44.)

La Téléphonie sans Fil par Ondes Lumineuses.—M. Chauvierre. (*Q.S.T. Français et Radio Electricité Réunis*, 7, 32, pp. 24-28.)

First part of a general description of the transmission of speech by light waves, dealing with early experiments on the subject.

Bildübertragung und Schnelltelegraphie (Picture transmission and high-speed telegraphy).—F. Schröter. (*Zeitschr. für techn. Physik*, 17, 9, pp. 417-428.)

Description of experiments on photo-telegraphy carried out by the Telefunken Company in conjunction with Professor Carolus. Illustrations of apparatus are shown, also samples of photographs and text telegraphed.

Television.—J. L. Baird. (*E.W. & W.E.*, 3, 39, December, 1926, pp. 730-739.)

A paper read before the Radio Society of Great Britain on 26th October, 1926.

Wireless Progress.—C. L. Fortescue. (*Electrician*, 12th November, 1926, pp. 563-564; *E.W. & W.E.*, December, 1926, pp. 740-742.)

Abstracts of the Chairman's address at the opening meeting of the Wireless Section of the Institution of Electrical Engineers on 3rd November.

The B.E.S.A. Glossary.—G. W. O. Howe. (*Electrical Review*, 5th November, 1926, p. 778.)

A letter in reply to that of Prof. Fortescue in the *Review* of 24th September, p. 523. Prof. Howe explains that his criticism was directed less to the system of units employed than to confusion in its use, particularly to the failure to distinguish clearly between electric force and flux density. This latter is criticised in the *Review* of 12th November, p. 818, by Mr. F. T. Fawcett, who points out that in it Prof. Howe makes "force" mean "work"; and again in the *Review* of 19th November, p. 831, Prof. Fortescue asks for the *physical* difference between field strength and flux density.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto - Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

R000.—SENFADENO ĜENERALE.

R050.—RESUMOJ KAJ ALUDOJ.

Kompilita de la Radio Research Board (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

R060.—MALFERMO DE LA SEZONO DE LA INSTITUCIO DE ELEKTRAJ INĜENIEROJ.

Mallonga raporto estas presita pri la malferma kunveno de la 1926-7a Sezono de la I.E.I. (Londono), kiam la nova Prezidanto, Dro. W. H. Eccles faris sian prezidantan paroladon. La parolado temis la esploron kaj komparon de la ĉefaj kampoj de moderna elektra disvolviĝado.

R200.—MEZUROJ KAJ NORMOJ.

R240.—LA ABSOLUTA MEZURADO DE REZISTECO JE RADIO-FREKVENCOJ.—R. M. Wilmotte.

La aŭtoro unue diskutas la malfacilaĵojn de altfrekvencaj rezistecaj mezuroj, kaj montras ke, se kurento estas pasigita tra bobenon posedantan rezistecon, la tuto de la energio dispelita estos liberigita kiel varmo, tiel ke la rezisteco estas mezurebla per mezurado de la kurento kaj la varmo kreita. Diversaj metodoj uzitaj por fari ĉi tiun mezuradon estas diskutitaj, kaj la aŭtoro priskribas metodon utiligi bobenojn laŭ formo de bobeno de vitra tubo plenigita je hidrargo. Unu ekstremaĵo estas fermita, kaj la alia finiĝas per kapilara tubeto, sur kio estas du markoj, kelkajn centimetrojn apartaj unu de alia, tiel ke la bobeno fariĝas ĝia propra termometro. Du tiaj bobenoj estas faritaj, kaj oni donas grafikaĵojn por la K.K. kaj A.F. normigoj por ĉiu. La rezistecoj tiel kalkulitaj estis uzitaj por kontroli la ordinarajn rezistec-variadajn metodojn de mezurado, kun tabelo de komparaj rezultoj, dum la bezono por zorgeco je tiaj mezuroj estas emfazigita. Vario de la terma metodo por la mezurado de kurento je tre altaj radio-frekvencoj estas ankaŭ sugestita.

R300.—APARATO KAJ EKIPAĴO.

R351.—NOVA METODO POR OBTENI FREKVENCAN STABILIGON DE SENDILO PERE DE OSCILA KVARCA KRISTALO.—C. W. Goyder.

Post enkonduka diskutado pri la fenomeno de sinkronizado, oni rimarkas, ke je agordita-anoda agordita-krada tipo de oscilatoro sub 200 metroj, ne estas necese kupli la bobenojn senpere, la valva kaj hazarda kuplo sufiĉanta. Cirkvito tiuspeca estas uzebla kune kun kvarc-kristala kontrola oscilatoro, la cirkvito estante permesita oscili propravole je proksimume la kristala frekvenco, dum sinkronizo kun la kvarca oscilatoro konservas stabilecon de frekvenco. La apliko de ĉi tiu principo al amplifikatoro funkcianta je malgrand-potenca (ekz., ¼ ĝis ½ k.v.) sendilo, estas montrita kaj diskutita. Oni pretendas, ke la aranĝo donas pligrandan efikecon al la ne-oscila tipo de amplifikatoro. Ĉiuj sendilaj cirkvitoj havas krad-cirkviton, al kiu la kristale kontrolita aparatero estas kuplebla; tial la metodo estas nur aldona kaj neniaj ŝanĝoj estas necesaj ĉe la ekzistanta sendilo. Por plimallongaj ondolongoj, harmoniko de la kristala frekvenco povas esti simile uzita, tiu ĉi aranĝo ankaŭ estante ilustrita kaj diskutita. Oni faras ĝeneralajn rimarkigojn pri la alĝustigo de sendila amplifikatoro ĉi tia, kaj pri la ĝenerala funkciado de kvarckristala kontrolado.

R381.4.—PLUAJ NOTOJ PRI LA LEĜOJ DE VARIEBLAJ AERAJ KONDENSATOROJ.—W. H. F. Griffiths.

La artikolo estas daŭrigo de antaŭa kontribuaĵo de la sama aŭtoro (*E.W & W.E.*, Januaro 1926a), en kiu oni kunmetis formularon por la platformoj necesaj por doni definitivajn leĝojn kunrilatigantajn Ondolongan (aŭ Frekvencan) kaj Angulan Movadon.

La nuna artikolo diskutas la okazojn kiam simila rilatigo estas dezirita, je kiu la kondensatoro estas uzita kun multa ekzistanta kapacito paralele aŭ serie je ĝi.

Koncerne paralelan kapaciton, oni diskutas la okazojn pri variebla kondensatoro de 16 $\mu\mu$F minimume, kaj 480 $\mu\mu$F maksimume, kiam ĝi estas kunligita paralele kun "pliigantaj" kapacitoj de 20, 84, kaj 284 $\mu\mu$F respektive. La formo de la platoj por doni linian ondolongan leĝon en ĉiu okazo estas montrita.

La okazo pri seria kapacito estas tiam diskutita sub la rubrikoj: (1) Platformo por Rektlinia Leĝo de Kapacito, (2) Platformo por Korektita Kvadrata Leĝo de Kapacito, t.e., Rektlinia Ondolongo, (3) Platformo por Inversa Kvadratleĝo de Kapacito t.e., Rektlinia Frekvenco, (4) Platformo por Konstanta Procenta Ŝanĝo de Ondolongo kaj Kapacito. Oni kunmetas esprimojn por la platformo en ĉiu okazo, kaj la diversaj formoj ilustritaj. Fina tabelo tre nete resumas la kvar okazojn.

R500.—APLIKOJ KAJ UZOJ.

R586.04.—TELEVIDADO.—Prelego de S-ro. J. L. Baird, legita de Leŭt.-Kol. J. R. Yelf, antaŭ la Radio-Societo de Granda Britujo, je 26a Oktobro, 1926a.

Kiel enkonduko, la aŭtoro unue diskutas la

lumrespondon de selenio kaj foto-elektraj ĉeloj, kaj la optika ago de la homa okulo. Sekvas mallongaj raportoj pri la plifruaj eksperimentoj pri Televidado, t.e., tiuj de Rignoux kaj Fournier, Rhumer, Rosing, Campbell Swinton, k.t.p., kaj la plimalfrua laborado de Belin kaj Holweck, Jenkins, Moore, k.c. Skizo pri la sistemo de l'aŭtoro tiam sekvis, kaj oni diris, ke de la unuaj sendoj de lumo kaj ombroj, figuroj de diversaj objektoj, inkluzive de la vivanta homa vizaĝo, estis senditaj kun duontonoj kaj detaloj. Fotografaĵo de unu el la figuroj estis donita, kaj oni diris, ke la difektoj estas grade forigitaj.

Diskuto kiu sekvis la legadon de l'prelego estas ankaŭ presita.

R599.—Senfadena Disvolviĝado Depost la Milito.—Resumo de la malferma parolado de Prof. C. L. Fortescue, Prezidanto de la Senfadena Sekcio, Inst. de Elek. Inĝ. farita ĉe la malferma kunsido de la Sekcio je 3a Nov. 1926a.

La lekcio estis dediĉita al kritikema revuo pri la disvolviĝo de la senfadeno dum la pasintaj sep jaroj, la progresado pri Sendiloj, la Senda Medio, kaj Riceviloj, estante diskutita.

Rilate al Sendiloj, oni diskutis la progresadon de la Arko, A. F. Alternatoro, kaj, la Grandpotenca Valvo. Koncerne la Sendan Medion, la agoj de la reflekta tavolo ĉe longaj kaj mallongaj ondoj estis komparitaj.

Pri Riceviloj, oni unue diskutis la Antenon "Beverage"; poste ricevilan selektivecon, atmosferaĵojn, k.t.p. La stato de brodkastado estis fine revuita, kun aludo al interfero de la komerca ŝipa trafiko.

R800.—NE-RADIAJ TEMOJ.

510.—Matematikoj por Senfadenaj Amatoroj.—F. M. Colebrook.

Daŭrigita el la antaŭaj numeroj. La nuna parto daŭrigas pri la Ĝenerala Ekvacio de la *n* Grado, kaj poste traktas Samtempajn Ekvaciojn por du Nekonitaj Numeroj, de la unua kaj dua gradoj, k.t.p.

535.—La Enkonduko de Natrio kaj Kalio en Disŝargajn Tubojn.—Dro. J. Taylor.

Oni donas priskribon pri metodo enkonduki puran natrion aŭ kalion en vakuigitan disŝargan tubon per speco de elektrolizo tra la vitraj muroj. La bulbo estas trempita en fanditan natrian (aŭ kalian) nitraton varmigitan en metala (ekz., aluminia) ujo, kiu estas igita la anodo de disŝarga sistemo kun la filamento kiel katodo. La pura metalo estas tiam aŭ demetita sur la internan muron de la vitraĵo aŭ vaporigita en la bulbon. Oni sugestas la eblecon ke, per variigo de la speco kaj konsistaĵo de la muroj, aliaj elementoj povus esti enkondukita je stato de granda pureco en tiajn vakuigitajn specojn. La metodo estas ankaŭ uzita per neona disŝarga lampo kun multa sukceso pliiganta ĝian stabilecon de funkcio.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

To the Editor, E.W. & W.E.

Plate-current, Plate-voltage Characteristics.

SIR,—Permit me to attempt to reconcile the views of Messrs. E. Fowler Clark and I. A. J. Duff on the above question.

To take the simple case where a low frequency transformer may be represented as a simple inductance and resistance in series, with no load on the secondary the magnification of valve plus

$$\text{transformer} = \mu.\frac{n_2}{n_1}\sqrt{\frac{X^2}{X^2+(R+\rho)^2}}$$

where μ = amplification factor of valve.
n_1 = primary turns on transformer.
n_2 = secondary turns.
X = primary reactance.
R = effective resistance of primary
and ρ = A.C. resistance of valve.

If we assume with Mr. Fowler Clark that reactance and resistance are both proportional to the square of the primary turns and write

$$X = an_1^2;\ R = bn_1^2$$

then (magnification)^2

$$= \mu^2\frac{n_2^2}{n_1^2}\cdot\frac{a^2n_1^4}{a^2n_1^4+(\rho+bn_1^2)^2}$$

From which it can easily be shown that :—

1. If the transformer ratio $\frac{n_2}{n_1}$ is constant then maximum amplification occurs when n is infinite, *i.e.*, infinite primary impedance.

2. If the transformer secondary turns n_2 is constant, maximum amplification occurs when the transformer impedance equals the resistance of the valve.

If we consider the more practical case where the transformer is shunted by a condenser, either external or in the form of its own self-capacity, then two values are again found for the primary impedance of transformer combined with condenser, according as $\frac{n_2}{n_1}$ or n_1 is regarded as constant. The first relationship still gives us infinite impedance for maximum amplification. The second case, however, does not give us maximum amplification when the impedance of transformer, or transformer and condenser, equals the resistance of the valve. As evidence of this, consider the case where the transformer plus condenser show a capacity reaction and the impedance of the two, or transformer alone, equals the resistance of valve. By reducing the primary turns we will increase the impedance of the circuit, hence increase the voltage across the transformer primary and increase also the transformer ratio, thus giving an increased total amplification. This is obviously at variance with Mr. Fowler Clark's rule.

A statement by Mr. E. Green on page 470 of the August issue of *E.W. & W.E.* must be similarly qualified. The statement, "For amplifiers using tuned circuits maximum amplification occurs when the output power is a maximum for a given amplitude of grid voltage," requires some qualification.

If we consider a tuned anode circuit consisting of an inductance L in series with a resistance R, the whole shunted by a condenser C, then if R and L are regarded as fixed, and C is varied, the rule holds good. If, however, C is fixed so that $\omega^2LC = 1$, and R is varied then maximum amplification obviously occurs with minimum power output, when $R = 0$.

We must conclude therefore that the laws laid down by Messrs. Green and Fowler Clark are by no means generalities, and should indeed be accepted with a very liberal pinch of salt.

S. Farnborough. C. HOLT SMITH, B.Sc.

To the Editor, E.W. & W.E.

SIR,—I am surprised to read a letter in your November number from Mr. E. Fowler Clark, B.Sc., B.A., A.M.I.E.E., attempting to correct a letter by Mr. I. A. Duff, in which he still maintains that a transformer primary impedance should be equal to that of a valve in whose plate circuit it is connected.

The elementary theory of intervalve coupling is very simple to follow, and even in the more advanced form in which all the various factors entering, are taken into account, it should not be beyond the understanding of a technically trained man, and yet the above idea seems to persist.

The function of any method of intervalve coupling is to pass on the voltage applied to the grid of the first valve through the coupling, to the grid of the following valve, magnified and, as far as possible, a true copy. It is only voltage that is passed on and amplified. If the valves are being correctly used, there should be no current flowing in the grid circuit except that caused by the grid capacity to the filament or the self-capacity of the grid circuit. Any such current is a loss. When we come to the last valve, the state of affairs is somewhat different. The magnified voltage which reaches the grid circuit of this valve has to produce power in the plate circuit of the same valve, this power being necessary to work a loud-speaker to produce sound energy. The magnified voltage which we have obtained and applied to the grid of this valve acts purely as a relay, the energy being drawn from the battery feeding the plate circuit of this valve. This seems to me a clear statement of the case and Mr. Clark, to some extent, admits this, but then enters into a complicated and almost

unintelligible argument about maximum activity in the primary, and so on.

But there is another way of settling this matter apart from any question of theory or calculation. It is quite easy, as far as concerns the audio frequency stages, to measure the actual voltages obtained across the grid of each valve, and it is also comparatively easy to measure the impedance of the primary winding of the intervalve coupling, for example, an intervalve transformer for audio frequencies. If this is done it will be found that the impedance of the primary winding is smallest for the lowest frequencies, increases to a maximum at some intermediate frequency, say 1,000 cycles for a very good transformer, or up to 2,000 cycles for a poor one, and then fails off again as the frequency is increased beyond this point. If Mr. Clark will turn back to the October and November numbers of your paper for the year 1924, he will see a number of measurements made by Mr. Dye at the National Physical Laboratory.

Now a transformer I am interested in has, under the working conditions in a wireless set, an inductance of somewhere about 90 henries, which gives an impedance at 25 cycles (a very low frequency) of about 14,000 ohms. This, by measurement in the plate circuit of a valve whose impedance was 10,500 ohms, and whose amplification factor was slightly above 9, gave for the 25-cycle signal an amplification of **22**. Now, at about 1,000 cycles, the impedance of the primary winding of this transformer has increased to something of the order of 800,000 ohms, and the amplification of the valve and transformer then measured was **31·6**. Here Mr. Clark will see that when the impedance of the transformer primary was somewhere near equal to that of the valve (that is, 14,000 ohms against 10,000 ohms for the valve) the voltage amplification obtained of the valve and transformer is only 22, but when the impedance of the transformer (namely, 800,000 ohms) is enormous compared with that of the valve, the amplification is then at its greatest, namely, 31·6. I may say these sort of figures have been measured by myself on hundreds of occasions and have been measured by the same and by other methods by other experimenters who, as far as reputation is concerned, would be considered more important than myself. Hence, Mr. Clark has to solve this problem: When the impedance of the transformer primary matches that of the valve, the amplification obtained is quite low. This is not a question just of frequency; it is merely a question of the impedance of the winding against that of the valve at whatever frequency that may, in a particular transformer, be obtained. On the other hand, when the impedance of the primary is exceedingly high, the amplification you get is just that which you expect to obtain from the μ of the valve and the ratio of the transformer and is much greater than in the first case. The statement apparently made by Mr. Duff that the *transformer primary should be of the utmost possible impedance and not of equal impedance to the valve, is absolutely true.* I have made for experimental purposes a transformer whose primary winding had an inductance of over 200 henries and a ratio of 3½. At 25 cycles, the impedance, as Mr. Clark will be able to calculate, is of the order of 31,000 ohms, and so very much greater than the above mentioned valve, and the amplification obtained then was about 28 (I have not the exact figure by me as I made the measurements in Canada). Here we have a transformer with a primary impedance, at whatever frequency you care to take, much greater than anything which can be obtained commercially, giving a better amplification with a given valve than any commercial article would give.

Of course, we cannot go on indefinitely increasing the impedance of the primary of a transformer, because self-capacity is introduced, which will actually, at high frequencies, reduce the impedance and give for notes, say of 4,000 to 8,000 cycles, a lower amplification than is desirable. This, and the question of price and weight, sets the limit to the inductance which one can incorporate in the primary of a low frequency transformer.

I have written at some length hoping to have made the matter clear enough to convince those who still hold *the erroneous idea* that impedance of the primary of a transformer should equal that of the valve. At the best this seems a curious phrase because, as explained, the impedance of the primary of a transformer may vary from a very low figure up to three-quarters of a million ohms.

Stockport. ALBERT HALL, A.R.C.Sc.

Signal Fading.

To the Editor, E.W. & W.E.

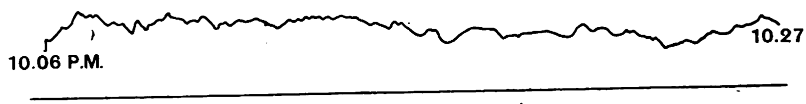
SIR,—Having been an observer of the variations of radio signal intensity with weather conditions for several years, I have been very much interested in the articles on signal fading and related subjects published in your journal in recent months.

Our laboratory is located almost in the geographical centre of the United States so that we are surrounded by rolling plains for at least 300 miles in every direction and are near no large body of water. Furthermore, stations at Denver, Dallas, New Orleans, Atlanta, Pittsburg, Cincinnati, Chicago and Minneapolis can be logged on almost any winter evening, and often we get Los Angelos on the west and New York on the east. For a number of months we have had in operation a signal-fading recorder which consists of a six-valve superheterodyne, in the last stage of which is a rectifying valve in series with a sensitive galvanometer. The galvanometer throws a beam of light through a right-angled prism on a rotating drum 30 cm. long and 8 cm. in diameter. The enclosed sample records show the general form of the curves obtained, the ordinates being proportional to the square of the received current and the abscissæ the time coordinates. These curves are also typical of the types of fading observed. The first from WHT shows unusually steady reception, the second from WCCO is long-period fading with 6 to 8 minutes between maxima, and the third from WOAI shows violent short period fading.

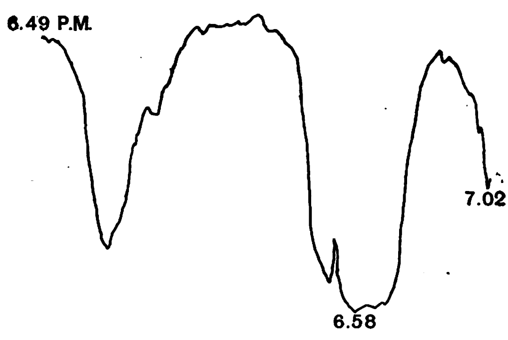
It is possible here to give only a few of the outstanding features of our experiments to date, one report on the earlier observations having already been published. (See *Radio Broadcast*, March, 1926.) We have found that on a night when fading is severe in one direction it also interferes with signals from other directions but usually

to a lesser extent. Fading may be most troublesome in one direction on one night and in quite another direction on the next night. It also is independent of the sending station. Contrary to Mr. Chapman's statement in his excellent article in the issue for September, 1925, we have on record some good coincidences in both magnitude and period of fading on WSMB recorded by our own apparatus and another stationed four miles west of us. The best conditions for radio reception as respects signal intensity, absence of static, and fading, occurs when transmission takes place along the ridge of an extended high-pressure area. With transmission at right angles to the isobars signal strength is also good but the signal-to-static ratio may be high.

So far as the influence of the moon is concerned we have collected no definite data, but it probably is of a second-order magnitude. Doubtless sunspot activity and penetrating radiations play an important part in determining the height and conductivity of the Heaviside Layer whose presence seems now to be proved by the experiments of Breit and others. The Heaviside Layer is above the isothermal region and much farther above the surface strata where storm phenomena and convection currents exist that the convolutions in this layer which are needed to explain fading on the Heaviside theory, or the variations in its density which are demanded by the Larmor hypothesis, must result primarily from causes outside the earth, or from variations in the earth's magnetic field. The latter view I have not seen previously suggested and I have not had available the necessary magnetic data to prove it, but it would at least help to explain the polarisation experiments of Dr. Pickard and the direction shifts recently observed by Professor Bidwell. Perhaps some of your English investigators have available the necessary magnetographic apparatus to check it up.



WHT 11TH SEPT 1925



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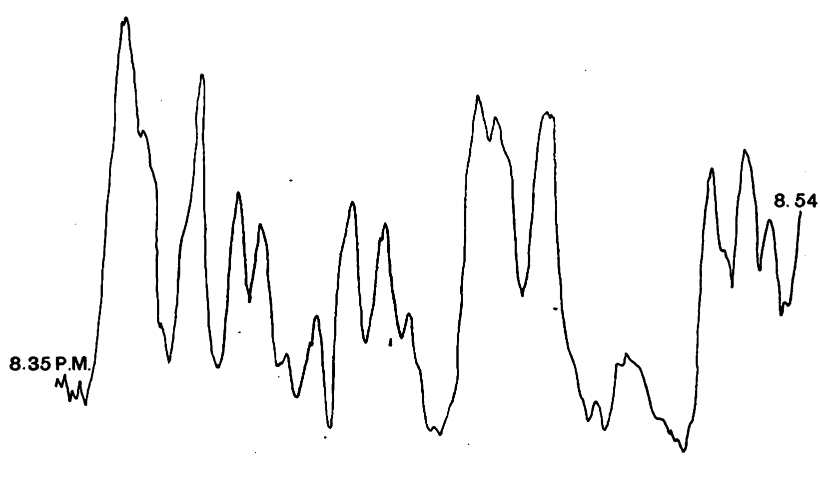


WOAI 3RD NOV. 1925.

J. C. JENSEN.
Nebraska Wesleyan University, University Place, Nebraska, U.S.A.

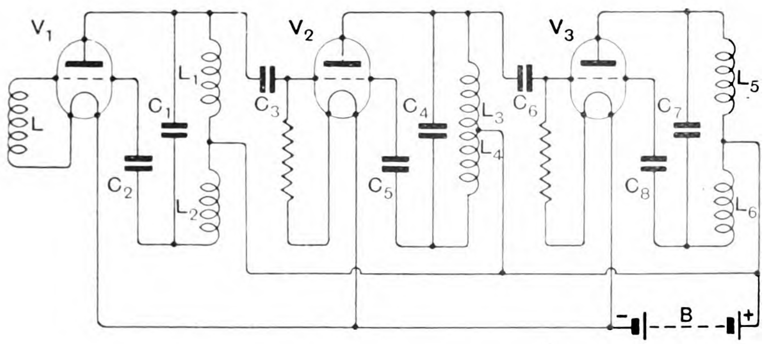
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each.

A NEUTRALISED AMPLIFIER.

(*Application date, 20th July*, 1925. *No.* 260,036.)

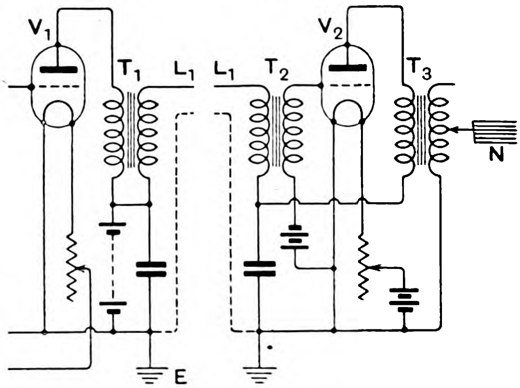
Those who are familiar with multi-valve amplifiers, employing several stages of neutralised intervalve coupling, will, no doubt, have experienced considerable difficulty in stabilising the arrangement, although each particular stage appears to be perfectly neutralised. A circuit which overcomes this difficulty is described in the above British Patent, No. 260,036 by H. J. Round, and consists essentially of a series of high frequency circuits, the inductances of which are alternately astatic and non-astatic. The arrangement of the three valves, V_1, V_2 and V_3, is shown in the accompanying illustration. The input of the first valve comprises an inductance L, while the anode circuit contains an astatic inductance comprising two portions, L_1 and L_2, that is, one inductance wound on a common former, the two portions being in opposition. The centre tap is taken to the high tension supply B, and the whole inductance is tuned by a variable capacity C_1. The anode end of the inductance L_1 is coupled to the grid of the next valve V_2 by means of a condenser C_3, while the other end of the inductance is connected through a neutralising capacity C_2, to the grid of the first valve. The anode circuit of the second valve V_2 includes an inductance L_3 L_4, which is non-astatic, that is, an ordinary centre tap coil which is coupled to the next valve V_3 through a condenser C_6, while the free end is taken through a neutralising capacity C_5 back to the grid of the second valve. The anode circuit of the next valve V_3 contains another astatic arrangement L_5 L_6, the arrangement being continued for other valves if desired. The oscillatory circuits associated with each valve are, of course, balanced, but since the inductances in the input and output circuits of each valve are different, there is no tendency for the generation of oscillations by the system as a whole, which frequently arises when the ordinary centre tap method is employed.



INDUCTIVE REPRODUCTION.

(*Application date, 6th August*, 1925. *No.* 260,061.)

Readers will, no doubt, remember that details were given in these pages in a past issue of *E.W. & W.E.* of a system of inductive reproduction described in a specification by G. W. Hale and R. Lyle. The above British Patent specification gives further details of a modification of the invention. The arrangement consists in using a powerful low frequency amplifier, the output of which is connected to earth, and a system of insulated overhead wires, a fairly strong low frequency alternating current field existing between the two. In order to receive the music it is only necessary to wear a pair of head telephones, the leads of which are of sufficient area or occupy sufficient space to cut



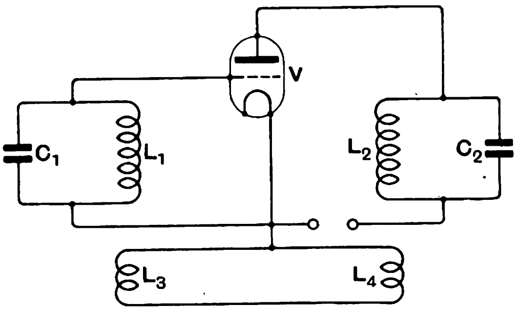
the field, and have produced in them low-frequency currents of appreciable magnitude. The present invention gives details of a convenient method for extending the system. For example, it may be necessary to have a distributing network in more than one room. It is not found convenient to

energise all the networks from one amplifier, and accordingly one network is electrically connected with another amplifying valve, and is used at the same time for supplying the high tension current. Thus, in the accompanying illustration the valve V_1 represents the last valve of the main amplifier, the anode circuit containing a transformer T_1 which is connected to a line L_1 and earth E. The line L_1 may also be connected to one of the distributing networks in some particular room. The continuation of this line L_1 is connected to an input transformer T_2, which is between the grid and filament of a valve V_2. The anode circuit of the valve V_2 deriving its power from the line contains an output transformer T_3, which, in turn, energises another frame or network N, located in another portion of the building. The usual batteries and other components of the valve circuits are quite normal, and are, therefore, not mentioned in detail.

NEUTRALISING MAGNETIC COUPLING.

(*Application date, 2nd July*, 1925. *No.* 260,324.)

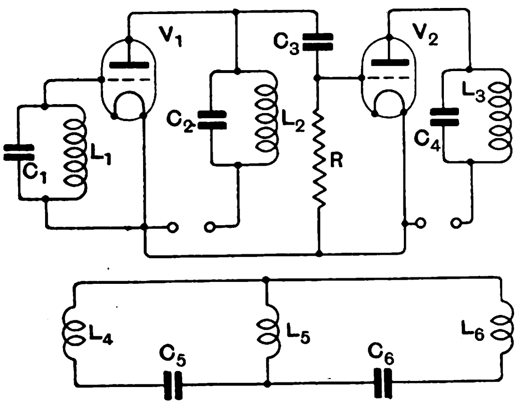
A method of neutralising magnetic coupling existing between the input and output circuits of a valve is described in the above British Patent by Igranic Electric Company, Limited, and P. W. Willans. The invention should be clearly understood by reference to the accompanying illustration, which shows a valve V provided with an input oscillatory circuit L_1 C_1, and an output oscillatory circuit L_2 C_2, the two being substantially equivalent. Owing to the disposition of the two inductances L_1 and L_2, it usually happens that there is an appreciable magnetic coupling between the two, and the mutual induction is frequently sufficient to sustain the generation of continuous oscillations by the valve at the frequency of the tuned circuits. The effect of this coupling is neutralised or overcome by the inclusion of two other auxiliary inductances L_3 and L_4, consisting of a considerably smaller number of turns than those used in the main inductances L_1 and L_2. The inductance L_3 is tightly coupled to the inductance L_1, and the inductance L_4 is similarly coupled to the inductance L_2. The two inductances L_3 and L_4 are then connected together so as to form a closed circuit, and they are so arranged that potentials transferred from the output circuit to the input circuit are such that they tend to oppose any regenerative effect between the input and output circuits. Another point to notice in the circuit is that the two inductances L_3 and L_4 are connected to the filament of the valve, thereby fixing their potentials in space with respect to earth, further tending to stabilise the arrangement as a whole.



NEUTRALISING CAPACITATIVE COUPLING.

(*Application date, 2nd July*, 1925. *No.* 260,325.)

The above specification, also granted to Igranic Electric Company, Limited, and P. W. Willans, is very similar to British Patent No. 260,324. In the former specification details were given of a system of neutralising inductive coupling, while in the present specification a somewhat similar system is used, only in this case it is the capacitative coupling which is neutralised. Previous methods of neutralising capacity have consisted in connecting, perhaps, one end of an anode inductance through a capacity to the grid of the valve, or, alternatively, connecting the grid of the valve through a small capacity to another inductance coupled to the anode inductance. The specification states that the disadvantage of this arrangement is that unless this capacity is very small it adds very considerably to the capacity either of the anode or grid circuit. The system employed according to the present invention is shown applied to a two-valve circuit in the accompanying illustration. Two valves V_1 and V_2 are shown connected together through the usual system of oscillatory circuits, where the input to the first comprises an inductance L_1 tuned by a capacity C_1. The anode circuit of this valve contains another inductance L_2 tuned by a capacity C_2. The anode end of this inductance is coupled through a capacity C_3 and a grid-leak R to the grid-filament system of the valve V_2. The anode circuit of the valve V_2 contains an inductance L_3 and a condenser C_4, the three oscillatory circuits being tuned to substantially the same frequency. The usual anode and filament batteries are omitted for the sake of clearness. Normally a system such as this would generate continuous oscillations owing to the inherent stray capacities existing between the input and output circuits of the valves. The stabilisation system consists of three inductances L_4, L_5 and L_6, which are respectively coupled to the inductances L_1, L_2 and L_3. One

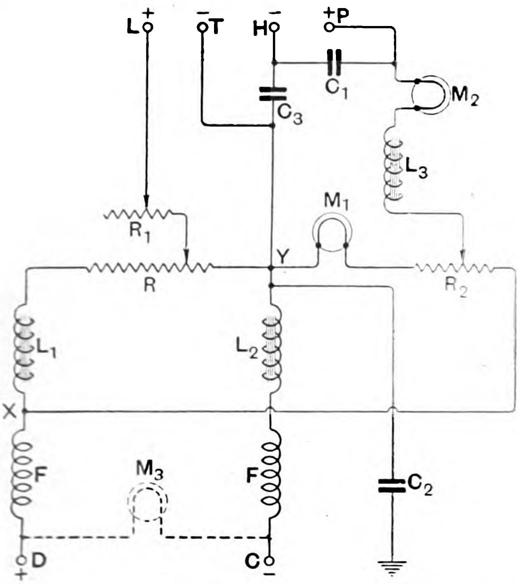


side of the three inductances L_4, L_5 and L_6 is common, while the free ends of L_4 and L_5 are joined through a capacity C_5, and the free ends of L_5 and L_6 are joined through another capacity C_6. The direction of the windings of L_4, L_5 and L_6 in relation to the inductances L_1, L_2 and L_3 respectively is so arranged that the induced currents tend to oppose regeneration between the circuits. In another modification of the invention instead of connecting the three inductances L_4, L_5 and L_6 directly together connection may be made through condensers.

MAINS SUPPLY.

(No. 259,260. *Application date*, 30*th April*, 1925, and No. 259,262, *Application date*, 8*th May*, 1925.)

G. G. Blake and L. Russell-Wood claim various circuital arrangements for mains supply to broadcast receivers in the above two specifications.

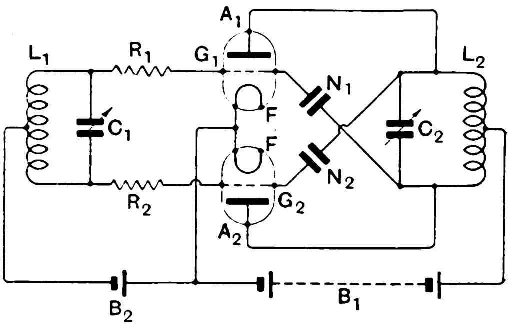


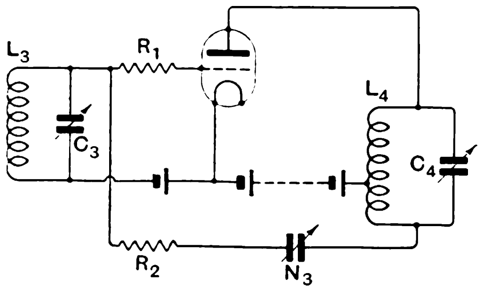
Perhaps the most important feature of the invention is the inclusion of radio-frequency chokes, and the accompanying illustration is taken from one of the specifications, which should indicate most of the chief features of the invention. The mains supply is shown at *D C*, which may be either the leads from a direct current supply, or from a rectified alternating supply. These are taken through high frequency chokes *F*. The filament supply is then taken through two iron-cored chokes L_1 and L_2, across which is a resistance *R*. The filament current is then drawn from *L T* through another variable resistance R_1, which is used for finer regulation. The high tension supply is actually taken across the points *X* and *Y*, *i.e.*, through both radio-frequency chokes, and the low frequency choke L_2. The resistance across the high tension supply comprises a lamp M_1 and a resistance R_2, the H.T. supply being drawn through the choke L_3 and another lamp M_2, the whole being shuntod by a large condenser C_1. A protecting condenser C_2 is included in the earth lead, which, of course, is usual practice. A similar safety condenser in the H.T. circuit is shown at C_3. Another feature of the two inventions which is dealt with in the former specification lies in the use of series resistances in the main positive high tension lead *P* for the purpose of obtaining varying voltages for separate valves in the receiving system. Another rather interesting feature of the invention is the use of a third lamp M_3, which, of course, glows brightly since it is directly across the mains, so as to indicate when the system is live.

STABILISING RADIO-FREQUENCY AMPLIFIERS.

(*Application date*, 29*th June*, 1925. *No.* 260,321.)

One of the greatest problems in radio-frequency amplifier design is that of stabilisation. Some of the earliest attempts at stabilising amplifiers consisted in increasing the damping of one or more of the circuits which, although preventing the generation of oscillations, was most inefficient, since it lowered the overall amplification, and also materially affected the selectivity. Balanced or neutralised circuits are preferable, since neither of these defects is present. Even with a carefully balanced circuit stabilisation is not always secured.





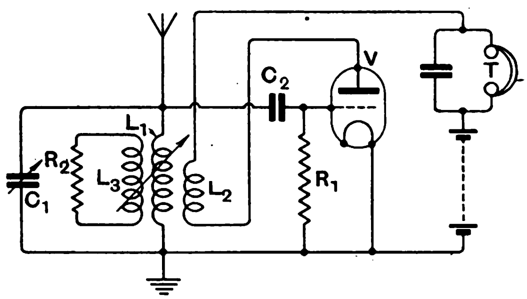
Why this is so, and how it may be prevented, is disclosed in the above British Patent, which is granted to G. M. Wright and S. B. Smith. It is pointed out in the specification that although a circuit may be electrically balanced when considered as a Wheatstone Bridge, and it would appear

that there could be no transference of potentials between input and output circuits of a valve, oscillations are even maintained under these conditions, and this, it is stated, is due to the fact that secondary oscillations are existent. These may pass from one tuned circuit through one valve, the second tuned circuit, the second valve, and back to the first circuit, and the balancing condensers do not prevent these oscillations taking place. The accompanying illustrations show how the secondary oscillations may be prevented by the inclusion of series resistances. One circuit is actually a two-valve push-pull arrangement. The input circuit comprises a centre tapped inductance L_1 tuned by a capacity C_1, while the output circuit is an inductance L_2 tuned by a capacity C_2, the inductance L_2 again being centre tapped, the anode potential being introduced at this point, while the grid potential is introduced at the centre tap of the inductance L_1, the two batteries being B_1 and B_2 respectively. The filaments F of the two valves are connected, of course, to the centre tap and common battery junction. The ends of the oscillatory circuit L_2 C_2 are connected to the two anodes A_1 and A_2. Neutralising condensers N_1 N_2 are included between the anode of one valve and the grid of the other. The secondary oscillations are prevented from occurring in the system by the inclusion in the two grid leads of resistances R_1 and R_2 respectively. The illustration also shows a single valve arrangement, which is, no doubt, more familiar. Here the input comprises an inductance L_3 tuned by a capacity C_3, while the anode circuit contains an inductance L_4, tuned by a capacity C_4. The anode battery is connected to a tapping of the inductance L_4, while the remote end is taken through a neutralising condenser N_3 to the grid of the valve. Stabilising resistances R_1 and R_2 are again inserted. The specification states that it is necessary in order that stabilisation may occur for the ratio of the inter-electrode capacity to the neutralising capacity and the resistances to be given by the product of R_1 and the valve capacity to equal the product of R_2 and the neutralising capacity.

CONTROLLING REACTION.

(*Application date*, 31*st July*, 1925. *No.* 260,359.)

A resistance method of controlling reaction where a special controlling circuit is introduced is described by N. H. Clough in the above British Patent. Only the theoretical circuit is shown in the accompanying illustration, but the specification gives details of certain constructional methods which are found preferable. Essentially, the invention consists in coupling a resistive circuit through a system which is generating oscillations, the coupling being increased until a sufficient amount of the resistance of the circuit is thrown back into the oscillatory circuit, thereby causing a cessation of the generation of oscillations. A very simple circuit is shown in the accompanying illustration, which should make the invention quite clear. Here the grid circuit of the valve V comprises an inductance L_1 tuned by a capacity C_1. The grid circuit also contains a grid condenser C_2 and grid-leak R_1. The anode circuit of the valve includes a reaction coil L_2 and the telephones T. The reaction coil is tightly coupled to the aerial coil L_1, the direction of the windings being such that the valve will continue to generate oscillations. The resistive control circuit which is shown as an inductance L_3 shunted by a resistance R_2, is capable of being variably coupled to the inductance L_1. The resistive control circuit may comprise one or more turns of resistance wire, or may comprise simply one or more turns of ordinary copper wire shunted by

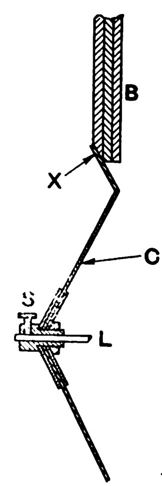


an ordinary resistance element. The specification also indicates other suitable forms of construction such as a number of closed circuits comprising one or more short-circuited turns of resistance wire. Another point which is mentioned in the specification is that when the invention is applied to a variometer the resistive circuit may be variably coupled to an inductance which is in series with one of the windings of the variometer.

A LOUD-SPEAKER DIAPHRAGM.

(*Convention date* (*U.S.A.*), 5*th January*, 1926. *No.* 258,502.)

The construction of a loud-speaker diaphragm is claimed in the above British Patent by Hopkins Corporation. The diaphragm itself consists of a cone C made of paper, provided with the usual form of collar and set screw S, by means of which it is connected to a driving link L, operated by the usual form of telephone receiver. The periphery of the conical diaphragm is bent back as shown at X, where it is united to the edge of a three-ply sound board B. The sound board has considerably greater area and mass than the conical diaphragm itself. A particular feature of the invention is the use of Balsa wood, which is exceedingly light and thin, and which is stated to improve very considerably the quality of the reproduction, particularly that of the lower frequencies. It is also mentioned in the specification that no explanation of this particular fact is suggested.



EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. FEBRUARY, 1927. No. 41.

Editorial.

The Performance of Amplifiers.

IN this issue we publish an article under this title by Mr. P. K. Turner in which he discusses the method of plotting the amplification curves of any device over a wide range of frequencies. Most of our readers will by now be quite familiar with the logarithmic or piano-keyboard method of plotting the frequencies as abscissæ. Since the change of pitch from 100 to 200 is musically the same as a change from 1,000 to 2,000, in that the change is an octave in each case, there is no need for the latter interval to be spread out over a base 10 times as long as the former. It gives a false impression of the distribution represented by the ordinates over the musical range. On the logarithmic scale each octave occupies the same extent of base line as on the piano keyboard. Very similar reasons may be adduced for plotting the amplification to a logarithmic scale. Doubling the loudness would then give the same change of ordinate whatever the initial value.

Mr. Turner gives curves of amplification at various frequencies of three sets, one a typical better-class English set, the second a set made by the firm with which the author is associated—giving naturally a better curve than the first—and thirdly a laboratory set. The author is quite fair, however, and points out that in the first set quality has been sacrificed somewhat to get range, and, moreover, that the quality as judged by broadcast reception was much better than one might expect from the curve.

There is one point, however, about all the tests to which we would draw attention and that is, that although they were obtained on sets consisting of a detector and two amplifying valves, for the purposes of these tests the connections were modified so that the first valve acted as an amplifier, thus converting the set into a three-valve amplifier. Why the author adopted this peculiar procedure does not appear from the article. It would have been more convincing if the audio-frequency tests had been made on the stages designed for audio frequencies, or if it were considered essential to use all three valves, the detector could have been supplied with a radio-frequency voltage of constant amplitude but modulated at various frequencies. This would have greatly complicated the measurements, however. The curve of Fig. 1 makes one curious to know what component of the set was responsible for the badness of the curve.

Radio-Frequency Measurements.

OF all the books published during 1926, the most important to the radio experimenter was probably Moullin's *Radio-Frequency Measurements* — described as a Handbook for the Laboratory and a Textbook for the Advanced Student.

As we felt sure that many of our readers who attempt accurate measurement of the varied magnitudes involved in their experimental work would consult the pages of this book, we decided to ask an expert in this subject to read the book and prepare a critical review of it for *E.W. & W.E.* Nobody has a more intimate, complete, and up-to-date knowledge of the theory and practice of high-frequency measurement than Mr. D. W. Dye of the National Physical Laboratory, and we have therefore much pleasure in publishing in this issue his review of Mr. Moullin's book.

Quality in Broadcast Reception.

THIS subject has recently been brought into prominence owing to one or two men of eminence in the musical world publishing statements which are far from complimentary to those who, like ourselves, are so deficient in musical taste that we actually enjoy a good broadcast performance of a Beethoven symphony or a Wagner overture. We can understand and sympathise with Sir Thomas Beecham when, in his disappointment and disgust, he looks around for something to kick and lights upon broadcasting. But surely he made his sad experiences in the financing of Grand Opera before broadcasting was dreamt of! The difficulties of making grand opera and high-class concerts a financial success may have been increased by broadcasting, but it is too early to give any definite judgment on the question. Mr. Ernest Newman, well known as a pungent and fearless musical critic, has also made an attack on wireless music from what one paper described as his lofty pinnacle in the *Sunday Times.* "The only people," he says, "who have a right to be heard on the subject of wireless music are perfectly impartial and disinterested musicians. In a matter of transmission of music by wireless only the musician's hearing, which is rather different from that of the scientist, is worth taking into consideration. What does the average scientist or wireless 'fan' know about orchestral timbres?" To which we would reply that the average scientist knows as much or more about these matters as the average impartial musician. It is a branch of science and one which has received considerable attention during the last few years.

No one would maintain that the reproduction obtained from even the best loudspeaker is perfect; it is not; but it is far too good to call for cheap jibes at the musical taste of the people who enjoy it. The progress made since the inception of broadcasting has been very great and still continues. We are living in a wonderland where millions of people hear the very best music several times every week and are learning to appreciate it and enjoy it—people who for the most part would never have heard it and to whom Beethoven, Mozart and Wagner would have been mere names. Surely this should be a cause for rejoicing rather than for criticism of the imperfections necessarily associated with such a novelty.

The Design of a Heterodyne Type Low Frequency Generator.

By H. L. Kirke.

As a certain amount of interest has been displayed in the design and performance of heterodyne type low frequency generators, it is thought that the details of design, and the experiments leading up to design, will be of use to those wishing to construct such instruments.

The author, and some members of his staff, commenced work on the design of a generator of low frequency currents just over two years ago, for use in connection with measurement work on Lines, Transmitters, Amplifiers, etc., used in broadcasting. The required performance was as follows :—

1. Maximum output 0.5 watt.
2. Frequency range 50 to 10,000 cycles.
3. Constant output over frequency range.
4. Waveform, close approximation to sine wave.

Various direct methods were tried, *i.e.*, a valve oscillating at the frequency required, but it was found that if the required performance was to be closely adhered to the apparatus would be unwieldy and far from simple in operation. It was therefore decided to carry out some experiments with the heterodyne method.

Two oscillators were constructed, working round about 4,000 metres, one variable in frequency, one fixed, the outputs connected to a rectifying detector and the resultant low frequency passed through a suitable amplifier. The output was measured by means of a slide back valve, which will be described later. The degree of harmonics present was determined by means of an A.C. bridge, in which the fundamental frequency was balanced out ; under these conditions it was possible to estimate roughly the amount of harmonic present in different arrangements, at any rate relatively.

It was necessary to use some form of aperiodic coupling between the H.F. generators and the detector, in order that the amount of H.F. applied to the detector should not change with frequency. Untuned coupling coils were employed for this and found satisfactory.

Various forms of detector were tried, grid-leak, crystal and anode rectification. It was found that anode rectification was by far the best from the point of view of freedom from harmonics, but at the same time great care had to be taken that there was no grid current in this detector, otherwise it was little better than the crystal or the grid-leak. Even by using the anode rectifier the harmonics were rather stronger than desirable.

The next step was the improvement of the high frequency waveform. In this connection it is of interest to note that harmonics can only occur in the resultant rectified current if both the high frequency carriers have harmonics. Also that in heterodyne reception, if one current is stronger than the other, the resultant rectified current is proportional to the weaker of the two (assuming a linear rectifier). Let A represent the amplitude of the strong carrier and B the amplitude of the weak, then peak amplitude of the combined carrier wave varies between $A+B$ and $A-B$. The peak value of the resultant rectified current (low frequency) will be proportional to the difference between the two, *i.e.*,

$$(A+B)-(A-B)=2B.$$

That is to say for a linear detector the amplitude of the rectified beats is unaltered by a change in amplitude of the stronger carrier. The same applies to a non-linear detector, provided that the one carrier is sufficiently strong to sweep right over the non-linear portion on to the straight portion of the detector characteristic, and that the amplitude of the weaker carrier is not sufficient to cause the instantaneous value of the resultant rectified current (D.C.) to reach a non-linear portion of the characteristic.

Now a rectifier arranged in this manner will not of itself introduce any harmonics into the resultant low frequency output, as the waveform of the low frequency output will be a copy of the envelope of the high frequency input.

The next consideration is the elimination of harmonics in the low frequency output

due to other causes, the chief of which are harmonics in the high frequency currents. It can be shown very simply that if both the high frequency currents contain harmonics then the resultant low frequency current will also contain harmonics, but if the harmonics are eliminated from one of the high frequency currents then the low frequency currents will contain no harmonics.

Consider two high frequency currents of frequency f_1 and f_2 having harmonics of $2f_1$ and $2f_2$, etc., respectively. Now f_1 and f_2

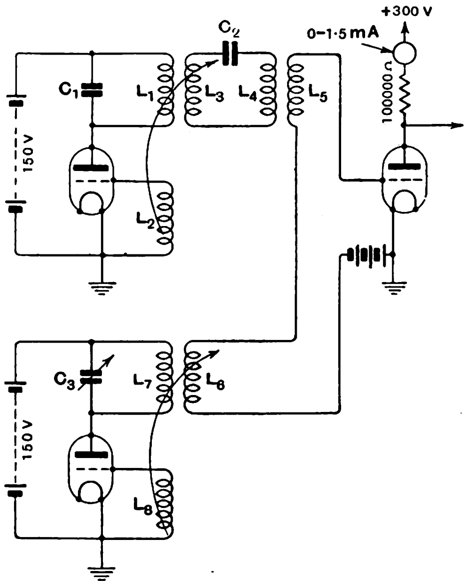


Fig. 1. *Diagram of connections of oscillator and detector.*

produce a beat frequency of $\pm f_1 \mp f_1 = f_3$; $2f_1$ and $2f_2$, etc., will produce a beat frequency of $2\,(\pm f_1 \mp f_2)$, etc. $= f_4 = 2f_3$, which is the second harmonic of f_3, etc.; $2f_1$ can also beat with f_2 and $2f_2$ with f_1 but the beats will be above audibility provided that f_1 and f_2 are far removed from f_3 in frequency. If, however, f_1 contains no harmonics, then $2f_2$, etc., has no complementary harmonic $2f_1$ of f_1 to beat with, in which case there will be no harmonics in the resultant low frequency current.

The next consideration is constant output at all frequencies. It has been shown above that if one high frequency is small compared with the other, and that the stronger one is arranged to sweep well over the non-linear portion of the detector characteristic, then the amplitude of the low frequency rectified current will be proportional to that of the weaker high frequency current. From this it will be seen that if the frequency of the weaker high frequency current is not varied, its amplitude should remain constant, therefore the amplitude of the resultant rectified low frequency current will be constant at all frequencies. The variation of frequency of the stronger carrier will probably produce variations of amplitude which, however, will not cause a variation of the amplitude of the low frequency output, provided that the variations of H.F. input amplitude are not sufficient to cause the rectifier to become non-linear.

It is convenient, therefore, to pass the fixed frequency currents through filter circuits, to remove harmonics as the adjustment of the filter circuits can be fixed. Very weak coupling can be used as the amplitude required is small compared with that of the variable frequency current.

The production of harmonics by grid current in the detector, as mentioned above, is due to the fact that the grid circuit of the detector is not tuned to the high frequency input, any non-linearity in the grid circuit will therefore produce harmonics in the high frequency currents and consequently in the low frequency output of the detector, as has already been explained. If it could be arranged that the input circuit consisted of a highly resonant (*i.e.*, very lightly damped) circuit, then any harmonics would be passed to earth very freely; in practice, however, this cannot be done, as the input circuit to the detector must be aperiodic to obtain constant amplitude output at all frequencies.

Fig. 1 shows circuits embodying the above principles.

The circuit on the top left is the fixed oscillator, the values L_1 C_1 were chosen so that oscillations generated were as free as possible from harmonics, C_1 being about 0.005μF for a wavelength of 4,000 metres. Larger condensers and smaller inductances could conveniently be used provided that lower resistance coils were used. L_3, the intermediate coupling coil, consists of a few turns of wire, loosely coupled to L_1. L_3 C_2 L_4 are tuned to the same frequency as L_1 C_1 and should constitute a very low damped

circuit. L_5 was a few turns tightly coupled to L_4 at the earth end. L_7 C_3 constitute the variable frequency oscillator C_3, being actually a fixed condenser of about 0.005μF plus three variable condensers in parallel, one of 0.00025μF capacity to adjust the zero, one of 0.00025μF to adjust the frequency difference (*i.e.*, resultant low frequency) up to 3,000 cycles, and another of 0.001μF for frequencies up to 10,000 cycles.

The valves used for the oscillators were L.S.5B's, but valves of similar characteristics worked very well. An L.S.5B has a resistance of 30,000 ohms, and a μ value of 20.

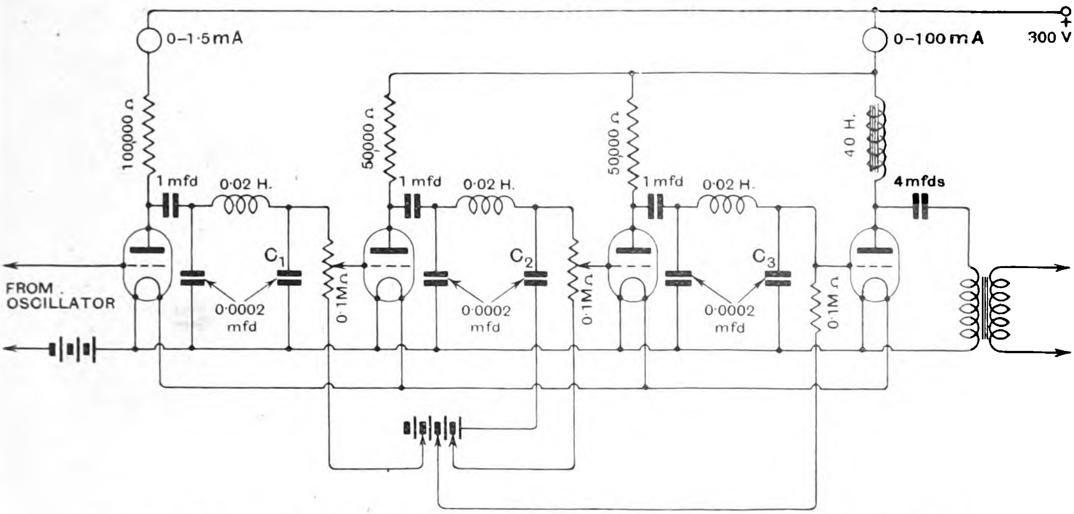


Fig. 2. *Diagram of connections of detector and L.F. amplifier. The output stage may consist of a number of valves in parallel.*

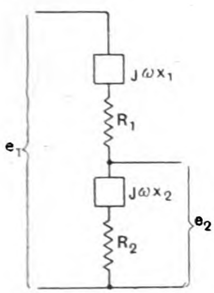


Fig. 3.

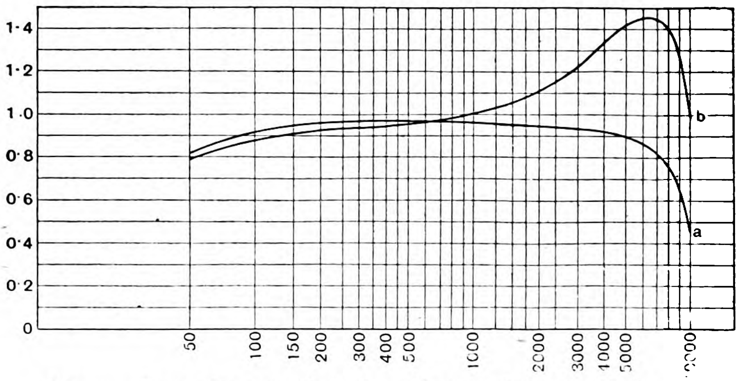


Fig. 4. *Curve showing effect of reactively and non-reactively wound potentiometer.* a = *non-reactively wound and* b = *reactively wound.*

It was found necessary to have considerable separation between the two oscillators to prevent one from pulling the other; the actual separation being about 5 ft. Three sets of H.T. and L.T. batteries were used for the first instrument built, one for each oscillator and one for the detector and low frequency amplifier. It was necessary to use separate batteries to prevent pulling.

The Low Frequency Amplifier.

As the range of frequencies to be covered was large, and constancy of output over the frequency range important, resistance

capacity amplification was used throughout, and low resistance valves (6,000 ohms, μ value 6) in order to obtain very linear characteristics, and so freedom from harmonics. Volume control was obtained by a wire wound potentiometer used as a grid-leak to one or more stages, the total value being 100,000 ohms, having 14 tappings, one potentiometer having a stud to stud ratio of 1 : 2, another having a ratio of 1 : 1.05. From this any known value of output relative to a known maximum could be obtained. For a detector valve the L.S.5B was found best, it having a sharper bend than most valves. The anode resistance was 100,000 ohms, the H.T. 300 volts. The anode current was adjusted by means of the grid bias, so that with no H.F. input it was about 0.3 to 0.4 milliamps, the H.F. input bringing the feed up to about 1 milliamp; 300 volts was used throughout in order that sufficient output could be obtained without introducing non-linearity. It was found necessary to insert H.F. chokes and

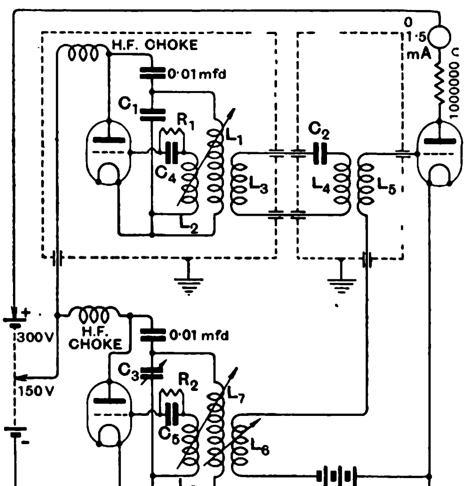


Fig. 5. *Diagram of connections of portable model oscillator unit.*

bypass condensers in the intervalve coupling, to prevent the carrier frequencies getting through the low frequency amplifier; these were approximately 0.02 henry and 0.0002μF respectively, and are shown in Fig. 2. It is necessary to adjust the values fairly carefully, in order not to alter the output frequency curve, a too high value of inductance producing a "tip up" of the high frequencies when the choke and grid filament capacity approach resonance. This

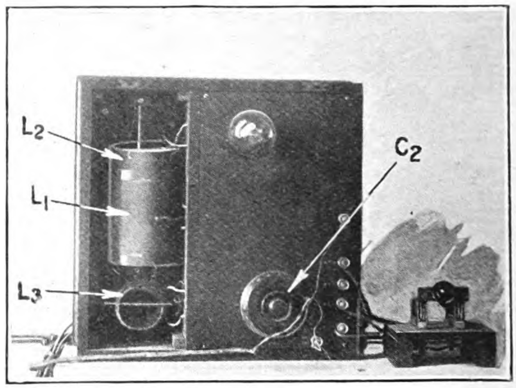


Fig. 6. *Fixed oscillator and filter circuit of first experimental model. The letters refer to Fig. 1.*

is analogous to resonance in an inter valve transformer due to magnetic leakage and capacity. The effect can be reduced by altering the value of grid-leak resistance and/or the condensers C_1 C_2 C_3 (Fig. 2).

It was also found necessary to take great care that the volume control potentiometers were non-reactive, as reactance in the windings may cause the output to vary with frequency and to vary differently for different settings of the potentiometers.

If a potentiometer is reactively wound, the ratio of reactance to resistance may vary with different settings of the potentiometer, if this happens the frequency characteristic will vary with different settings, as follows: In a potentiometer, as shown in Fig. 3, the ratio of output E.M.F. e_2 to input E.M.F. e_1 at any frequency $\omega/2\pi$ will be :—

$$\frac{e_2}{e_1}=\frac{1}{1+\dfrac{R_1+J\omega X_1}{R_2+J\omega X_2}}$$

Now if

$$\frac{R_1}{J\omega X_1}=\frac{R_2}{J\omega X_2}$$

then the frequency characteristic will be straight, but if the ratio

$$\frac{R_1}{J\omega X_1} \text{ to } \frac{R_2}{J\omega X_2}$$

is not constant over the whole range of the potentiometer, then the frequency characteristic will *not* be constant. Fig. 4 shows the effect of a reactively wound potentiometer.

the potentiometers should be of the order of 50,000—100,000 ohms and 44 S.W.G.—Eureka wire, silk covered, may conveniently be used.

If it is desired that the frequency characteristics shall be straight at low frequencies

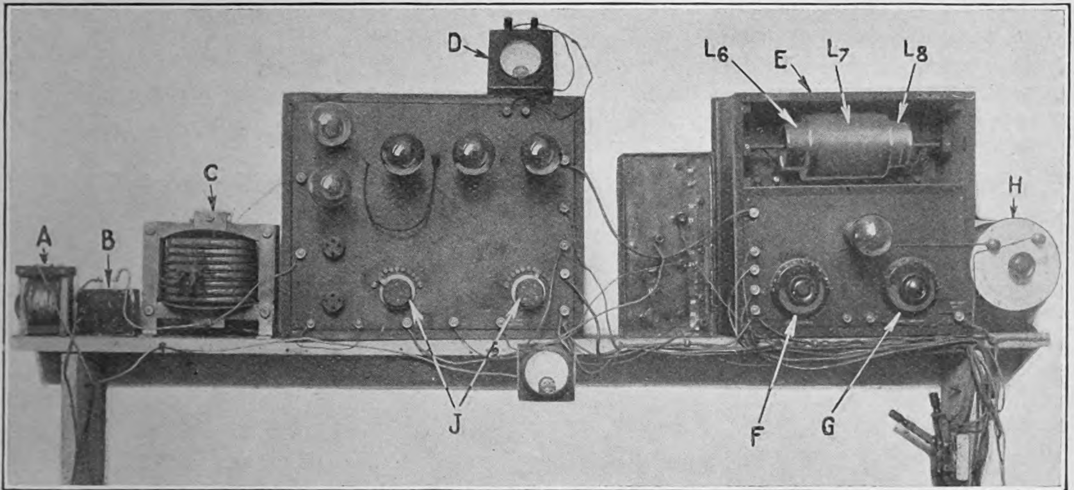


Fig. 6A. *Variable frequency oscillator on right, detector and L.F. amplifier on left. (First experimental model.)* L_6, L_7 *and* L_8 *refer to Fig.* 1. F, G *and* H *comprise the variable part of* C_3 *(Fig.* 1). D = *shunted galvanometer for detector feed.* J = *Potentiometers.* C = *Anode feed choke.* B = *Output condenser.* A = *Output transformer.*

A convenient method of winding potentiometers is to use a bobbin with a large number of sections, arranging that the resistance between each stud on the potentiometer shall be split up into several sections, alternate sections should then have the direction of winding reversed. The total resistance of

of the order of 50 p.p.s., then intervalve condensers should be not less than $1 \mu F$ capacity each.

A portable form of heterodyne generator was also constructed, in which the H.F. oscillator circuits were screened. Great care must be taken that the circuits are effectively

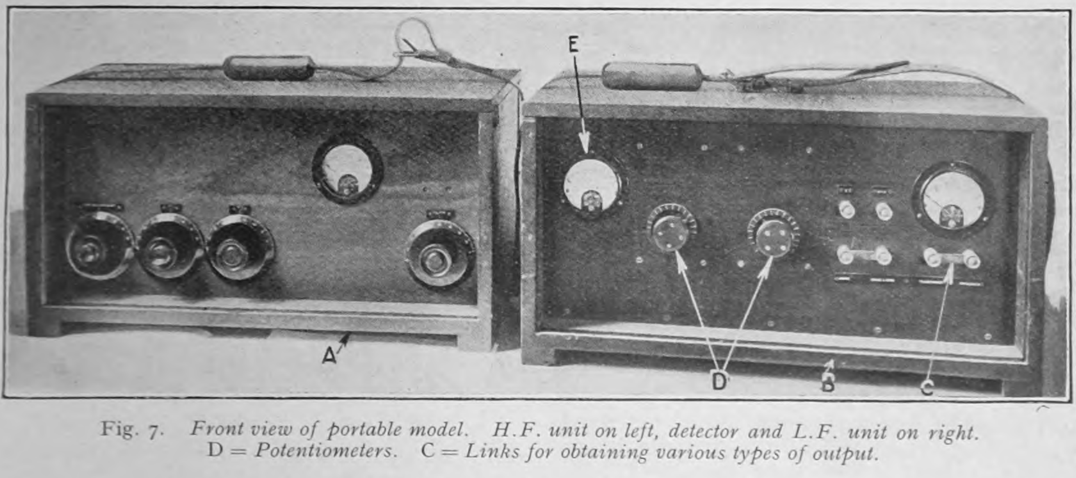


Fig. 7. *Front view of portable model. H.F. unit on left, detector and L.F. unit on right.* D = *Potentiometers.* C = *Links for obtaining various types of output.*

screened, and that there is no coupling between the circuits of the fixed frequency oscillator and those of the variable frequency oscillator. Even with a good copper screen, if L_1 is close to L_7 (Fig. 5), as is necessary for compactness, the axes of the coils must be carefully arranged to reduce magnetic coupling to a minimum. Parallel feed was used with the valves as shown in Fig. 5 to prevent the H.F. current flowing through the H.T. battery, so reducing the amount of pulling taken off the 300-volt battery for the H.F. valves, also common L.T. (6 volts). Fig. 6 shows the fixed oscillator and filter circuit; Fig. 6A shows the variable frequency oscillator on the right and the detector and L.F. amplifier on the left. In Fig. 7 the two oscillators and the filter circuit are in the left-hand box, the detector and amplifier in the right-hand box.

A model has since been constructed, the details of which are as follows, the references

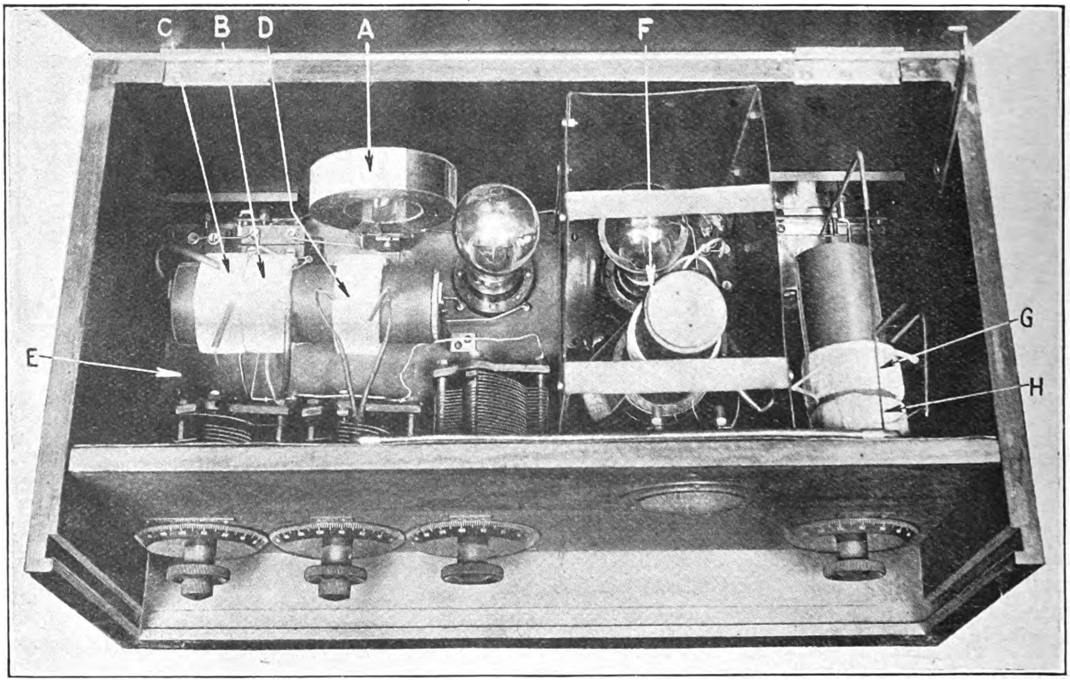


Fig. 7A. *View showing interior of high frequency unit.* A = *Anode choke.* B=L_7. C=L_8. D=L_6. E=C_3 (*variable part*). F = L_1, L_3 *and* L_2. G = L_4. H = L_5. *The references are to Fig.* 5.

due to resistance in H.T. battery. The H.F. chokes should have high inductance and low self capacity. Where constancy of frequency is of importance it has been found an advantage to use grid condensers and leaks in both the H.F. oscillators as shown in Fig. 5 (C_4, C_5, R_1, R_2), C_4 and C_5 are both 0.001μF, R_1 R_2 are both 100,000 ohms. Photographs of the apparatus are shown in Figs. 6 and 7.

Figs. 6 and 6A show the original model and Figs. 7 and 7A the portable model. For the portable model common H.T. was used throughout, the tapping of 150 volts being being to Fig. 5: all coils are 2 in. inside diameter and $\frac{3}{16}$ in. thick, slab wound outwards.

H.F. Chokes, each 3 sections, each 700 turns No. 36 D.W.S.

L_1 and L_7	80 turns	9/40	Each strand s.s.c. and D.S.C. overall.	680μH
L_2 and L_8	40 ,,	,,		170 ,,
L_3	1 turn	,,		
L_4	61 turns	,,		330 ,,
L_5	10 ,,	,,		14 ,,
L_6	15 ,,	,,		30 ,,

C_1 0.005 fixed approx.

C_2 0.01 fixed + 0.001 variable.

C_3 0.005 fixed + 2/0.00025 variable + 1/0.001 variable.

Operation.—As the frequency of the two oscillators is liable to vary with H.T., L.T., temperature, etc., it is necessary to have some means of adjusting them to be relative to each other. This is best done in practice by the zero adjusting condenser. The two tuning condensers are both set at zero, and zero adjusting condenser adjusted until the beat frequency, as indicated by the milliammeter in the detector anode circuit, is zero. The actual movement shown on this meter for

Constancy of Frequency.

It was found subsequently that the instruments remained sufficiently constant in frequency under the conditions specified above, for all ordinary purposes; at any rate, the changes in frequency were of a minor order compared with the accuracy obtainable by the calibration curve and the condensers.

It was found that the amount of harmonic

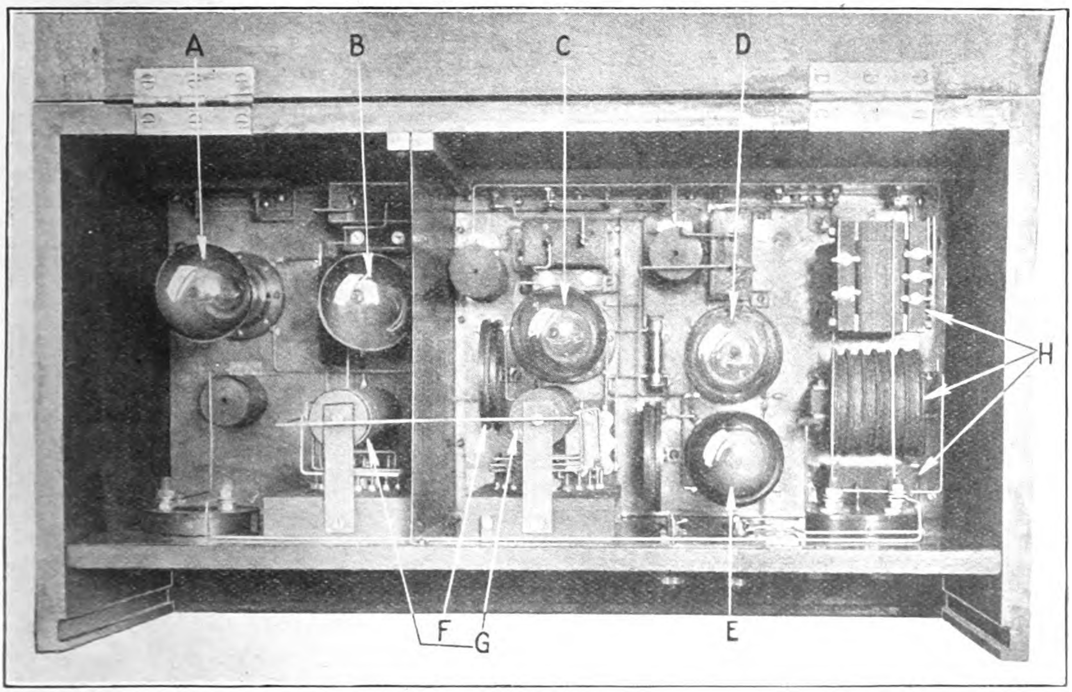


Fig. 7B. *Detector and L.F. amplifier of portable model.* A = *Detector valve.* B = *1st L.F.* C = *2nd L.F.* D *and* E = *Output stage* (2 *valves in parallel*). F = *H.F. Stopping choke.* G = *Potentiometer bobbins.* H = *Output choke condenser and transformer.*

frequencies of the order of one or two a second, is an indication of the amount of pulling between the two oscillating valves, *i.e.*, if there is pulling the movement will not be sinusoidal. Frequencies from 0 to 3,000 are obtained by adjusting the first condenser between 0 and 180 degrees. This condenser is then left at 180 degrees and the second condenser varied up to 180 degrees for frequencies up to 10,000. Calibration curves and output frequency curves are shown in Figs. 8 and 9.

varied between $\frac{1}{2}$ per cent. and 5 per cent., according to frequency and amount of output required, *i.e.*, linearity of amplifier. This amount has been estimated, not measured directly.

Measurement of Frequency.

Before this apparatus had been constructed a frequency bridge was made and calibrated. Two methods were tried, circuits of which are shown in Figs. 10 and 11. In Fig. 10 a condenser shunted by a resistance is

balanced against a condenser in series with a resistance, the balance can only be obtained at one frequency. In Fig. 11 an inductance

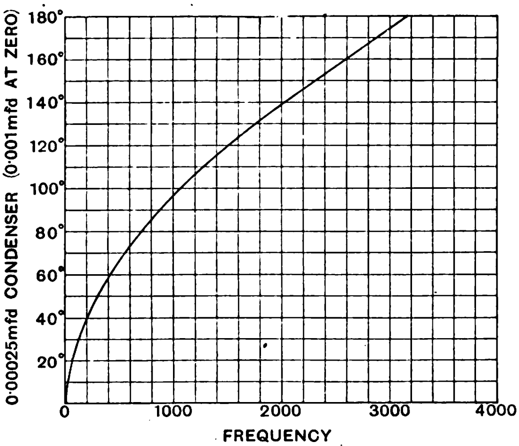


Fig. 8.

and condenser in series form one arm of a Wheatstone bridge. When

$$L.C. = \frac{1}{(2\pi f)^2}$$

the inductance capacity arm is non-reactive, and can be balanced at that frequency as a resistance. This form of bridge was found to be the more satisfactory, and one was built which could be balanced at frequencies from 64 to 8,000 cycles per second. The inductance consisted of a number of power transformer sections, any number of which can be thrown into circuit by means of Kellogg switches. The condensers are preferably of mica, but paper condensers may be used. The actual values used on the bridge were as follows :—

R_1 100 ohms.
R_2 350 ohms.
R_3 400 ohms variable + 25 ohms variable for fine adjustment.
L 0.075, 0.25, 0.55, 1.4, 2.5, and 4.5H.
C 0.01 to 1.5μF in steps of 0.01+a continuously variable 0.01μF condenser, or 0.001 to 1.5μF in steps of 0.001, + a variable 0.001μF condenser.

Calibration.

The instrument was calibrated by means of a standard tuning fork and two separate oscillators, which could be tuned to harmonics of each other. By this means a number of points were obtained and the calibration curve plotted.

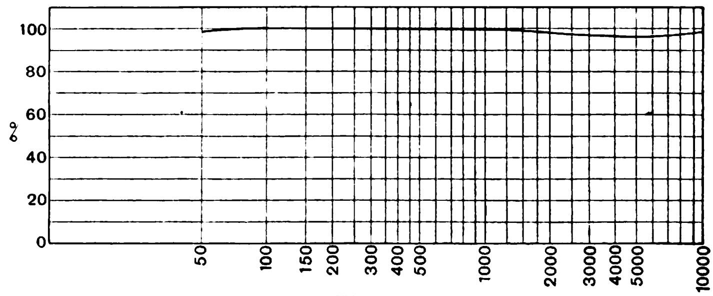


Fig. 9.

The tuning fork had a frequency of 428 cycles per second. One oscillator was tuned to this frequency by the zero beat method and the bridge adjusted to this frequency and readings taken. The second oscillator was then tuned to twice the frequency and another point taken. The first oscillator was then tuned to one-third the frequency of the second oscillator so that its second harmonic coincided with the fundamental of the second oscillator, and so on.

Intermediate points were taken by means of adjusting the oscillators to notes on a piano. The frequency of the notes being known by counting

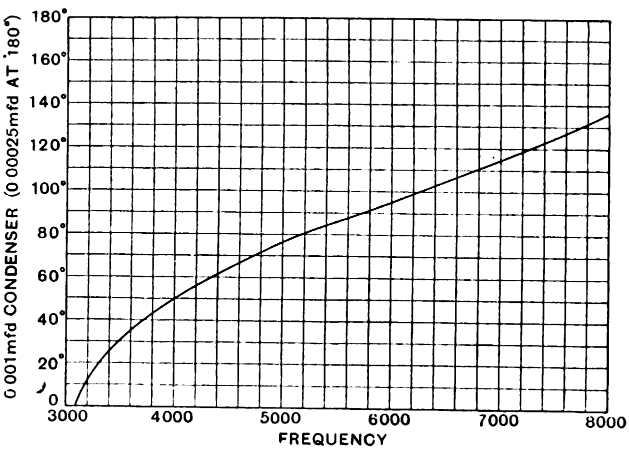


Fig. 8A.

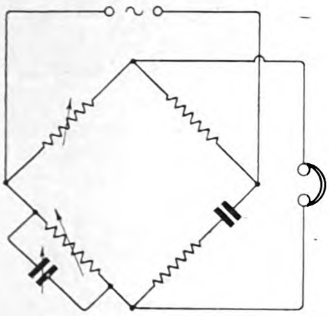


Fig. 10.

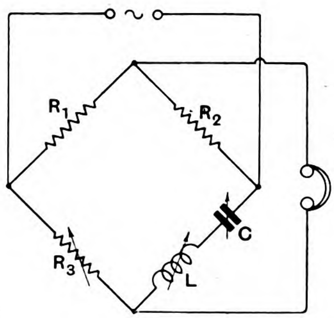


Fig. 11.

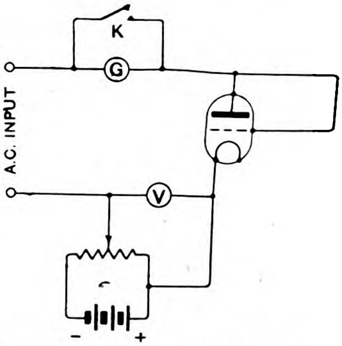


Fig. 12. *Connections of slide back.*

beats between the note of the piano and a tuning fork. While this last method may seem rather crude and unsatisfactory, it was found in practice to be extremely good, provided care was taken.

Measurement of Output by Slide Back.

The slide back as used consisted of a three-electrode valve type D.E.R. with the grid and plate strapped. This was connected as shown in Fig. 12. If the D.C. potential difference across the potentiometer

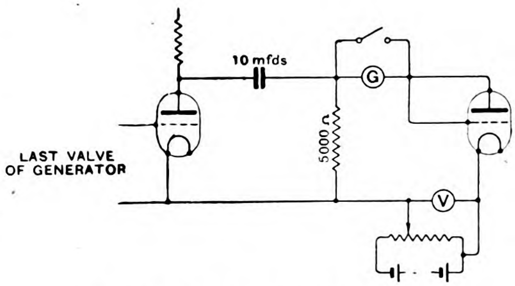


Fig. 13. *Connections of slide back.*

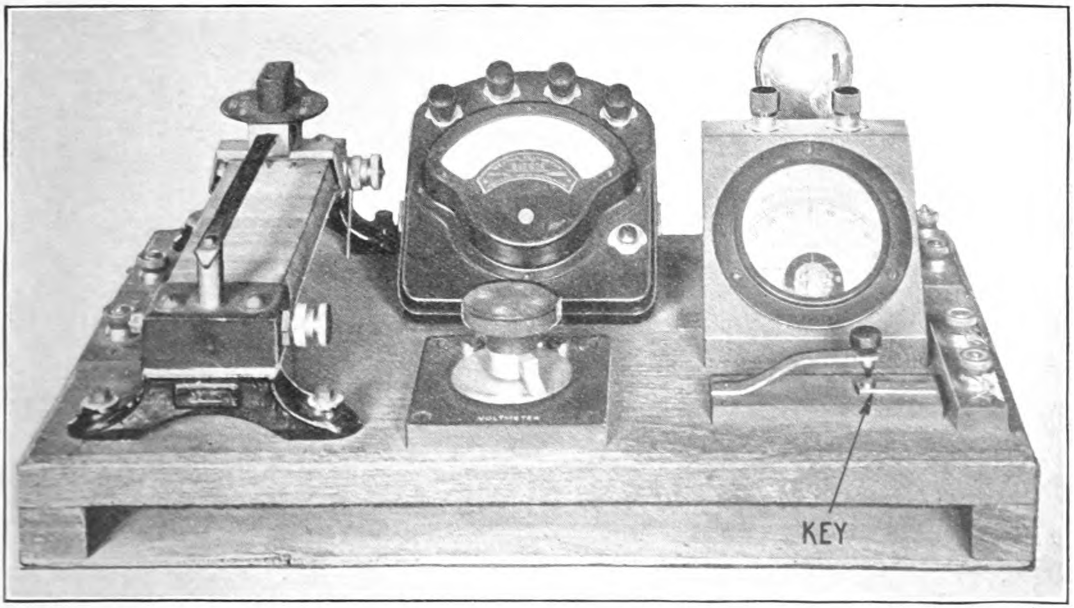


Fig. 14. *View of slide back unit.*

is so adjusted as to be equal to the peak value of applied alternating voltage no current will flow through the valve. The key is used to short circuit the galvanometer, this is used to increase the sensitivity of the instrument, *i.e.*, adjustment of the potentiometer is made until there is no movement in the galvanometer when the key is depressed. A quick-moving galvanometer is essential.

This potential difference is therefore the peak value of the alternating voltage. It should be noted, however, that even with no A.C. a certain small negative potential has to be applied to the anode of the valve to reduce the current to zero. This value should be subtracted from the final value of voltage obtainable.

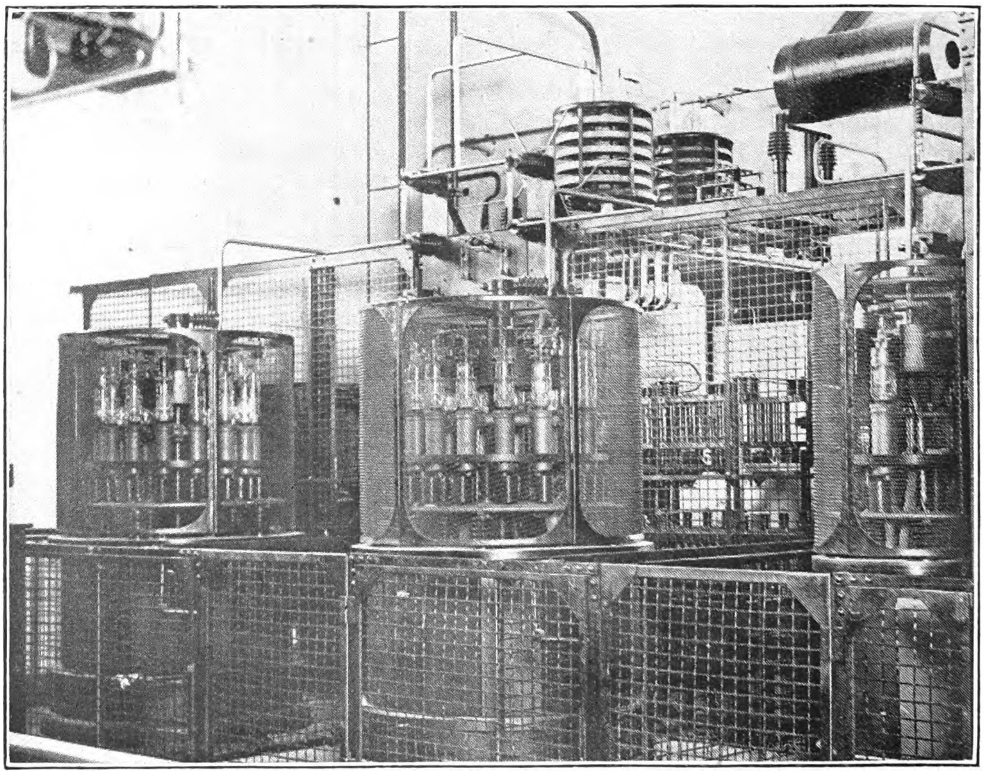
Method of connection to circuit is shown in Fig. 13.

Photograph of the slide back is shown in Fig. 14.

Another method of measuring output is to use a thermo-junction in series with some convenient resistance. This then becomes essentially a voltmeter.

The author wishes to thank Capt. H. J. Round, Messrs. G. M. Wright, M. M. Rust and P. W. Willans for their advice; also Mr. A. B. Howe and other members of his (the author's) staff for their co-operation and assistance.

Transatlantic Telephony Equipment.



The circular valve racks of the transatlantic telephony transmitter installed at Rugby. Each section accommodates sixteen water-cooled valves, the associated apparatus necessary when valves are parallel connected being assembled radially on the platforms.

The Performance of Amplifiers.

By P. K. Turner, A.M.I.E.E.

(*Research Department, Burndept Wireless Limited.*)

WHEN the first performance curves of intervalve transformers were published some two years ago, they were usually plotted to a vertical scale of amplification and a horizontal scale of frequency. It was soon realised, however, that this horizontal scale was quite unsatisfactory. If, as is desirable, the scale extends from zero to 10,000 cycles or thereabouts, the whole of the frequencies between 0 and 1,000—the range over which it is difficult to get the maximum amplification of a transformer—are cramped up on the left-hand side of the resulting graph, and although by carefully examining the graph one can, of course, find out just what the transformer does (assuming the curve to be correct), there is still no doubt whatever that the curve does not give to the eye a true picture of the performance. It is now well realised that such a graph should be plotted to a logarithmic scale of frequency, or, as one may prefer to call it, a simple scale of "pitch," and such is the universal practice nowadays.

Recently, however, the author has been taking some curves of the same nature relating to complete amplifiers, and as a result of this work it would appear that there is need for further modification in this type of diagram.

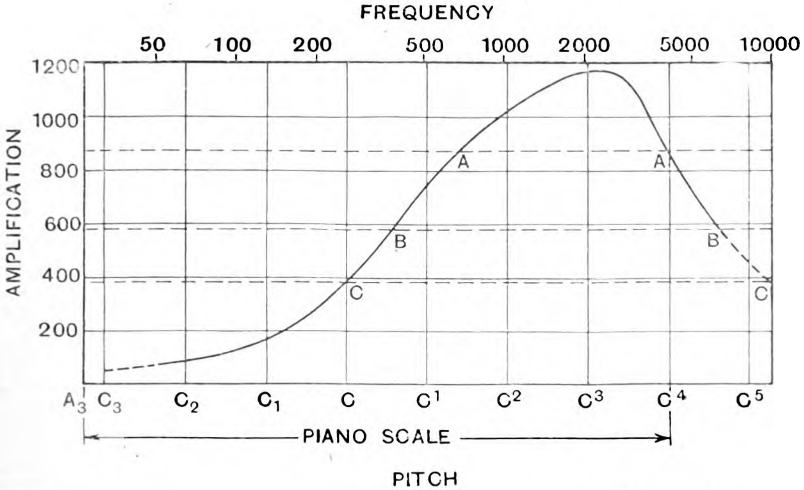


Fig. 1. *Amplification plotted against pitch for a set of indifferent quality. The three lines* AA, BB, *and* CC *indicate respectively amplifications of* 75 *per cent.*, 50 *per cent., and* 33 *per cent. of the maximum.*

For example, Fig. 1 shows the amplification of a commercial set as a function of pitch. This set may be regarded as typical of the general run of better-class English sets: in construction it is pretty much the same as dozens of sets exhibited at the last Olympia Show. Judging from the impression made on the eye by the curve, it would appear to be past all hope of giving a reasonable performance—one would expect to hear nothing except in the neighbourhood of 2,000 cycles. When, however, one comes to examine the curve in detail, one finds that it is much better than it appears, though

admittedly it is not good. For example, the smallest difference in amplification which can be perceived, even by a trained ear, without a rapid switch over for comparison, is a drop of 25 per cent. The line *AA* in Fig. 1 corresponds to this drop, and it will be seen that frequencies between about 700 and 4,000 cycles are satisfactorily amplified. This test, however, applies to test work, and is by no means a fair one for a broadcast set in actual use. It will be found that when listening to music it needs a drop in amplification of 50 per cent. before any noticeable impression is made upon the ear. The line *BB* in Fig. 1 represents this drop, and it will be seen that on this basis the set in question has a range of from 400 to 6,000 cycles approximately. But even this is a criterion on the severe side: a considerable amount of testing has shown that there is no obvious defect in the amplification (as regards domestic use) until the actual magnification falls to a third of the maximum. Line *CC* in Fig. 1 represents this, and may be regarded as the real limit of reasonably satisfactory performance; it will be seen that in this amplifier the total range of satisfactory performance is from about 250 to 10,000 cycles.

As we have stated above, a critical examination of any form of curve will give corresponding information regarding the component or receiver in question, but it cannot be denied that a curve which looks like Fig. 1 and yet represents a moderately satisfactory performance between 250 and 10,000 cycles is obviously wrong somewhere, for the shape of the curve as it presents itself to the eye would indicate much narrower limits.

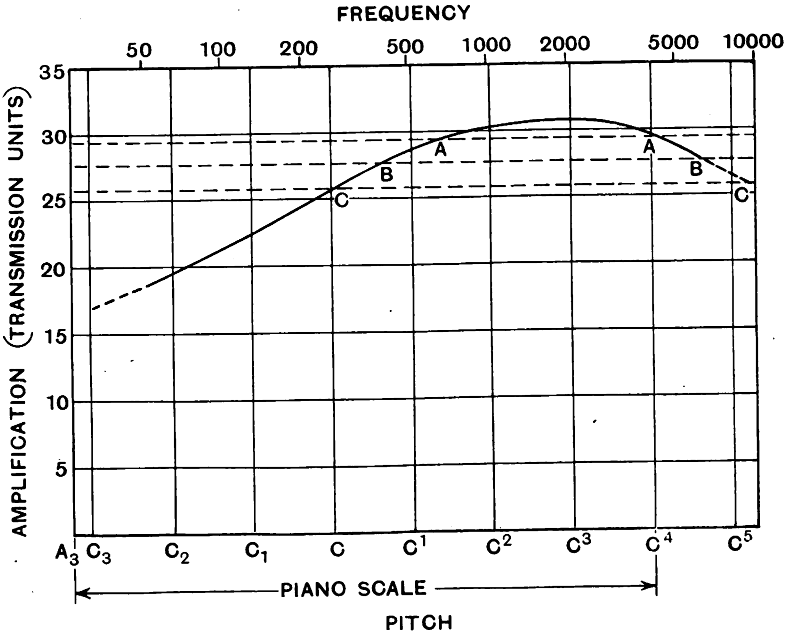


Fig. 2. *The same set as Fig. 1. "Gain" in Transmission Units against pitch. Lines* AA, BB, CC *and have the same meaning as in Fig 1. It is obvious that this curve conveys to the eye a truer picture than that of Fig 1.*

The writer would therefore suggest the adoption of what is already standard telephone practice, *i.e.*, that the vertical scale should be made logarithmic also. There is no doubt that the difference of impression made on the ear by two different volumes of sound is a matter of their ratio and not of their absolute difference; if we exhibit the performance with the vertical scale in "Transmission Units" (which in practice corresponds to a logarithmic scale in which

the logarithms are multiplied by 10, so that a thousandfold amplification is equal to 30 T.U.) we do get a much more reasonable curve. Fig. 2 shows a curve of the same set plotted in this manner, and it will be seen that the general appearance of the curve is much more consistent with the effective range. Without measurement, one might estimate by eye quite reasonably that its range of satisfactory performance would be approximately that which it actually possesses.

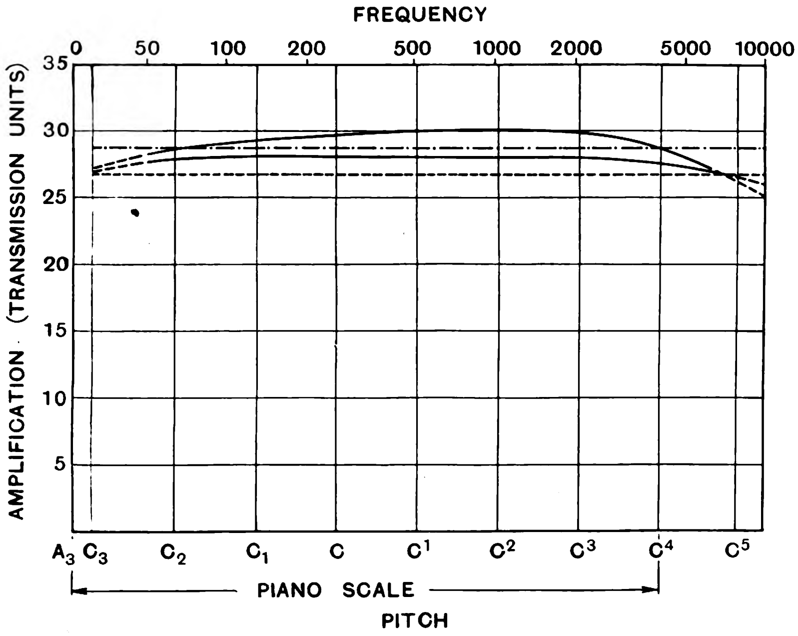


Fig. 3. *" Gain " against frequency for two sets of good performance. Upper curve, Burndept Ethophone III., Mark IV. Lower curve, laboratory-built resistance-coupled set. Chain dotted line represents 75 per cent. of full amplification for upper curve. Dash line represents same percentage for lower curve.*

It may be of interest to see for comparison what really well-designed apparatus could do, and the author therefore has shown in Fig. 3 the performance of a resistance-coupled amplifier of laboratory type, specially made to give good reproduction at the cost of sensitivity, and of a standard 1926-7 commercial three-valve set. It will be seen that the resistance-coupled set—which was measured mainly as a check upon the accuracy of the method—gives a range of frequencies between about 30 and 7,000 cycles with less than a 25 per cent. drop. The total amplification amounts to approximately 28 T.U., or in the neighbourhood of 630-fold. This performance is naturally better as regards frequency range than that of the commercial set, for which an amplification of 30 T.U. or 1,000-fold was absolutely necessary to satisfy the public demand as to the range of a three-valve set. It will be noticed that the latter has a range extending from about 70 to 4,000 cycles with a 25 per cent. drop and from about 30 to 7,000 cycles with a 50 per cent. drop. Unfortunately, measurement below 40 or above 6,000 becomes so difficult that the author has been obliged to extrapolate* the curves beyond these points. It would appear, however, that the commercial set will have a range before noticeable loss is observed of from approximately

* This extrapolation has not been done at random. It is known that the shape of such a curve at both extremes of the frequency range corresponds to a comparatively simple equation, the constants of which can be found from the values of the circuit components. Some of these latter, *e.g.*, stray capacities, are unknown, but can be found from readings actually made at high and low frequencies.

16 to 11,000 cycles, and even for the most critical ear a range of 30 to 7,500.

There are, however, still two traps in estimating the performance of a set from curves of this kind, both of which lead to an under-estimate of the set's performance in most cases. First one must remember that amplification curves of this kind are taken with a pure note supplied to the receiver. In practice, of course, the receiver is supplied with notes containing large quantities of harmonics, and owing to the non-linear response of the ear the impression of the fundamental is invariably conveyed to the brain by the Tartini difference tones. It may be estimated, therefore, that any set will give an impression of reproducing notes about an octave lower than those which it actually does give, although the reproduction of such notes will be not quite accurate.

set, and, second, the output from it. The diagram of connections is shown in Fig. 4, and it will be seen that with the switch *A* in the uppermost position the Moullin voltmeter is connected to a 2,000 ohm resistance, which, in turn, is linked to the audio source via the regulating potentiometer *B*. This latter was adjusted until the Moullin voltmeter showed exactly one volt. A twentieth of this voltage was thus applied to the first valve of the set by means of the resistances *C*. A loud-speaker of the type for which the set was designed was included in the output circuit, and also a resistance *R* of the order of 100 to 1,000 ohms. With the switch *A* in its bottom position, the Moullin voltmeter measured the voltage across this resistance, which was adjusted until the reading was the same as before, *i.e.*, one volt. From the value of *R* it is easy to calculate

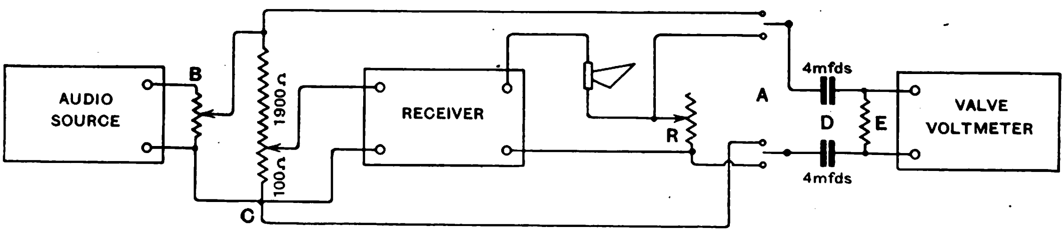


Fig. 4. *Theoretical diagram of connections for the measuring circuit.*

Secondly, the measurements were made (as is noted below) on a low-frequency input. It is notorious that both the use of a grid rectifier and the use of tuned circuits preceding the amplifier tend to accentuate the low notes to a certain extent, and therefore improve the performance in the bass.*

The method of measurement by which the results were obtained is extremely simple in theory, although not quite so easy to carry out in practice. For these measurements, which were all on three-valve sets, the first or rectifying valve had the grid lead connected to a point one volt below the negative end of the filament, so that it would amplify instead of rectify. A Moullin voltmeter was used to measure first the input to the

* The author hopes before long to show some results, based on a slightly different procedure, which will take account of these factors.

the alternating current in the anode circuit of the last valve, making a correction if necessary for the loss in the condensers *D* and leak *E* which isolate the voltmeter. (In practice this correction was never more than 0.1 per cent., and it was therefore neglected.)

An independent measurement was then made of the resistance and reactance of the loud-speaker over the whole range of frequency involved; to its resistance there were added the A.C. resistance of the valve and also *R*, so that the total impedance of the anode circuit was known, and from this and the current already found the total generated voltage in the output circuit was calculated. The figure of magnification given in the curves represents the ratio of this output voltage to the constant input voltage of 0.05 volt.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 28 *of January issue.*)

7. The Continuity of Functions.

THE idea conveyed by the group of symbols $y=f(x)$ has already been explained, but it has been considered hitherto from what may be described as the static point of view, *i.e.*, we have thought of y as a number the value of which depends in some specified manner on the value assigned to the independent variable x. ("Independent variable," by the way, is rather a mouthful. From now on we will use the older name "argument" instead. It is less explicit, but its meaning should be quite clear at this stage.) The other and rather more important aspect of the matter is suggested by the phrase "the *behaviour* of a function." It is, as it were, the dynamic aspect, and is concerned not so much with individual values of the function but rather with the succession of values corresponding to a continuous variation of the argument. Putting it in graphical terms, we are going to consider the shape and other characteristics of the line which represents the variation of y with x. The ideas we shall meet in doing so are among the most important in the whole of mathematics, and must be taken seriously by anyone who wants to cultivate a mathematical habit of mind as distinct from a specious fluency in the tricks of the trade.

To fix ideas we will specify the function in the form

$$y=10^{\frac{1}{x-1}}+1.$$

The graph, or picture, of this function is given in Fig. 15 for a range of values of the argument from $x=-20$ to $x=+20$. (Any such range of values is called "an interval" of values of the argument.) The most noticeable feature of the curve is that it appears to break up into two parts, the left-hand part terminating abruptly at the point for which $x=1$, while the right-hand part seems to come flying sheer down out of the blue, after the manner of an aeroplane attacking an observation balloon, "flattening out" along the line for which $y=2$. It is clear that something very drastic happens to y when x is given the value 1, and a more detailed examination of this region will be made later. Everywhere else the curve is a smooth, unbroken, continuous line without any sharp angles or sudden changes in direction, showing that y changes gradually

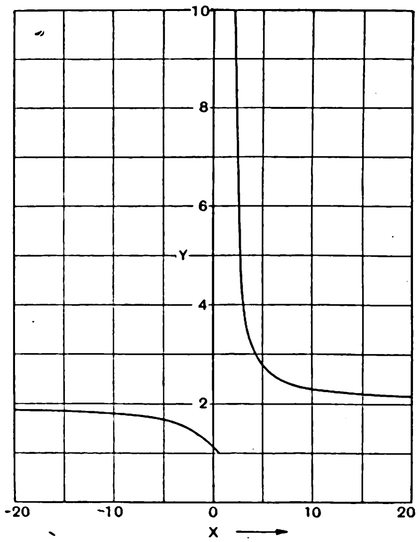


Fig. 15. *Graph of* $y=10^{\frac{1}{x-1}}+1$.

with x without any sudden jumps from a small to a large value or *vice versa* for a small change in x. Variation of this character is described as "continuous," and the function is said to be "continuous" through any such interval. On the other hand, a point at which there is an abrupt transition in value, such as occurs when x is given the value 1, is described as a point of "discontinuity," and the function is said to be "discontinuous" at any such point. It is obvious that in carrying out operations with

a function one must look out for such points, for certain operations which may be quite legitimate and safe in a region of continuity might lead to disastrous conclusions if the functions has a point of discontinuity in the interval concerned. To quote an example from Professor Whitehead, a man who walked over the edge of Shakespeare Cliff on the assumption that the height of the ground above sea level was a continuous function of his distance from Dover, would be dead before he had time to rearrange his ideas on the subject.

The continuity or otherwise of a function is therefore a matter of practical importance. That being so, we must try to find some exact description of what we mean by continuity, some test which can be applied over any region in which there is cause to suspect irregularity of conduct on the part of the function ; for although the above preliminary account conveys the general idea, those readers of this series who have acquired the fastidiousness in thinking which is essential for mathematics will certainly not be satisfied by so vague and woolly a description. "Gradually," for instance — what does "gradually" mean in terms of the fundamental ideas of mathematics ? The practical man might be tempted to reply that the variation of y is gradual over any region in which a small change in x produces a correspondingly small change in y. But what does "small" mean ? This is probably where the practical man begins to get annoyed ; but we can't help it. Common sense is *not* enough. It is essential to realise that there is no abstract quality of absolute largeness or smallness in numbers, or indeed in anything else, for all magnitude is relative. Even in ordinary conversation the word "large" is so vague as to be meaningless apart from its context, stated or implicit. When the Englishman says, "That is a large apple," he means that it is large compared with, *i.e.*, larger than, the average apple of his experience, and when the American replies, "Large ! Call that a large apple ?" he is presumably thinking of the pumpkin-sized affairs which he has no doubt could be found growing on his uncle's farm in California, if he had an uncle in California. Here is one and the same thing called large by one person and small by another, and such examples could be multiplied indefinitely to show that "large" and "small" are no more than current and convenient abbreviations for "larger than" and "smaller than." This is equally true of mathematics, which is, after all, no more than an idealisation of experience. Of two numbers, one can be smaller than, equal to, or larger than the other, and those are the only fundamental ideas about number which can be admitted in the description of a mathematical conception. Our description of continuity must, therefore, dispense with any absolute "large" or "small" and employ only those fundamental ideas about number on which the whole science of mathematics is based.

First we need some word which will serve to distinguish a point of a function from a restricted interval of values containing the point, *i.e.*, extending on either side of it. The word used is "neighbourhood." Notice particularly that a statement cannot be made about the neighbourhood of a point unless there is a finite interval of values, containing the point, of which the statement is true. Notice further that a statement made about the neighbourhood of a point may or may not be true of the point itself. Nothing is said about that when the neighbourhood is mentioned. It is in fact a very useful feature of the word "neighbourhood" that it distinguishes between the point and some restricted interval of values containing the point. Now take the function we are considering, *i.e.*,

$$y = 10^{\frac{1}{x-1}} + 1.$$

For the value 3/2 for x it is very easy to show that the value of y is 101 ; but we cannot say that the function has the value 101 in the neighbourhood of $x=3/2$, for there is no finite *interval* of values of x containing 3/2 of which this is true. But we can say that in the neighbourhood of $x=3/2$ y differs from 101 by less than .1, or, another way of saying the same thing, approximates to 101 within a standard of .1, because a finite interval of values of x can be found for which this is true. By a simple calculation which need not be detailed, it can be shown that y approximates to 101 within a standard of .1 for all values of x between 1.4999 and 1.5001. In the present instance we could be more exact still, and say that y approximates to 101 within a standard of .00001 in the neighbourhood of $x=3/2$, because again a

finite interval of values containing 3/2 can be found for which this is true, though of course it will be a very much smaller interval than before. Actually, however small the standard of approximation be taken, it can be shown that y approximates to 101 within that standard in the neighbourhood of $x=3/2$, and we can say at once that y approximates to 101 in the neighbourhood of $x=3/2$ within *every* standard. This is exactly what is meant by continuity. Expressed more formally the statement becomes: A function $f(x)$ is continuous for a value a of the argument when in the neighbourhood of the point for which $x=a$ its value approximates to $f(a)$ (*i.e.*, its value at a) within every standard. The full beauty of this definition will not perhaps be realised all at once, but it will repay thinking about, for it is a fine example of the precision of mathematical thought. A lawyer experienced in the difficulty of clothing ideas in words would recognise it with delight as a perfect fit.

The function we have been considering will pass this test at every point except that for which $x=1$, and is therefore said to be everywhere continuous except at $x=1$. It is not, of course, suggested that every function one encounters must be scrutinised all over with this sort of microscope. One soon becomes able to tell by inspection where critical variation is likely to occur. Such points will, generally, but not invariably, be associated with values of the argument for which zeros or infinities appear in some part of the functional expression. This does not make the matter academic, for though it is true that infinities do not occur in real life they frequently occur in the functions that we use as a convenient approximate representation of some particular slice of real life that we may be contending with. For instance, neglecting the resistance in a high frequency circuit calculation, may be both legitimate and convenient in general, but, by freeing the function of its ballast it may introduce the possibility of extravagant acrobatics for certain critical values of the frequency or of the circuit constants, and it is necessary to be prepared for such happenings.

8. Limits.

We will now consider the behaviour of the above function when x is given the value 1, and in order to see more clearly what is happening at this point we will examine the region with a magnifying glass. In other words, we will tabulate values of x and y through a restricted interval of values containing 1.

x	y
.9 .99 .999	$10^{-10}+1$ $10^{-100}+1$ $10^{-1000}+1$
1.0	?
1.001 1.01 1.1	$10^{1000}+1$ $10^{100}+1$ $10^{10}+1$

This shows that as the value 1 for x is approached from the less than 1 side y approxmiates more and more closely to 1. On the other hand, if the value 1 for x is approached from the greater than 1 side, y increases continually, and the closer x becomes to 1 the greater the value of y. The first set of values would lead one to suppose that y becomes 1 when x is 1, but the second set suggests that y becomes greater than any finite number when x is 1; but the function is single valued everywhere else, *i.e.*, for any given value of x there is only one value of y. Why then should it assume a sort of dual personality at this point? The answer is that it does not. At this point, on the contrary, it has no defined value at all, for it becomes

$$y = 10^{\frac{1}{1-1}} + 1 = 10^{\frac{1}{0}} + 1$$

and 1/0 is not a number at all. We saw in para. E4 of Section 3 (August, 1926) that the whole structure of mathematics would collapse if 1/0 were treated as if it were a number subject to the ordinary laws of arithmetic. This, then, is the first thing to notice about this point—that the function has no defined value at all when x is 1. But from the tabulated values it is clear that y has a definite value when $x=1-h$, however small h may be *provided it is not actually zero.* Moreover, it is clear that y can be made to

approximate to 1 within any desired standard, however small, by assigning a sufficiently small value to h. Under these conditions the function is said to have a finite limit when x tends to 1, although it has no defined value at all when x *is* 1. The idea can be expressed in various ways in symbols; for instance,

$$\underset{h\to 0,}{lt.}\ f(1-h)=1$$

which is quite explicit, or again

$$\underset{x\to 1-0,}{lt.}\ y=1$$

or

$$\underset{x\to 1-0,}{lt.}\ f(x)=1$$

where $x\to 1-0$ is taken to mean that the value 1 for x is approached from the less than 1 side. Notice particularly that in any case such as this, where the function has no defined value for a given value of the argument but nevertheless approaches a finite limit as the argument approaches this value, this finite limit is never actually reached, although the function can be made to approximate to it within any desired standard. This idea of a limit is of the utmost importance in mathematics, and has been the subject of much criticism and research, particularly in recent years. Unless the reader understands it thoroughly he can never hope for anything better than a dangerous rule of thumb knowledge of the calculus, so he is advised to go over this part again and again if necessary, until the understanding of it is assured. The formal statement of the idea is usually expressed in some such way as this: A function $f(x)$ is said to have a limit L for a value a of its argument if for every quantity k another quantity h can be found such that when x differs from a by less than h, $f(x)$ differs from L by less than k. This has always seemed to the writer a case where the definition was much harder to understand than the idea it defined. The reader need not stick over this definition, but must make sure of appreciating the idea as illustrated in the above example.

In the example quoted the limiting value is never actually reached, since the function has no defined value at the point; but the actual definition of a limit does not exclude the possibility of the limit of a function being the same as its value at the point concerned. In fact, if the reader has really understood the definition of continuity, he will see that it requires that the function shall have a finite limit for the given value of the argument, that limit being the same as the value of the function at the point. In general, however, the rather difficult conception of a limit is substituted for the simpler idea of the value only where it is really necessary, that is where the value does not exist.

So much for the behaviour of the above function when x tends to $1-0$. The behaviour on the other side of this point is quite different, though a somewhat similar idea is involved. The tabulated values show that y increases very rapidly as x approaches 1 from the greater than 1 side, and the reader should have no difficulty in seeing that y can be made to exceed any finite number by bringing x sufficiently near to 1. This is conveniently, though perhaps not very happily, expressed by saying that the limit of y under these conditions is infinity, *i.e.*,

$$\underset{x\to 1+0}{lt.}\ y=\infty$$

which really means that y has no finite limit at all and continues to increase without limit as x approaches 1.

Yet another kind of limit, the antithesis of infinity, is illustrated by this function. (It was chosen, of course, because of its versatility in this direction.) What happens when x becomes very large compared with 1? The index of the ten is $1/(x-1)$, and it is clear that as x becomes larger and larger this index will become smaller and smaller. By making x sufficiently large compared with 1, $1/(x-1)$ can be made smaller than any fraction of unity, however small. *It can never be made zero by increasing* x, but it can be made to differ from zero by as little as we please by making x large enough compared with 1. Here, then, the conception of limit comes in again, and we say that the limit of $1/(x-1)$ is zero when x tends to infinity, *i.e.*,

$$\underset{x\to\infty}{lt.}\ \frac{1}{x-1}=0$$

It is sometimes stated in text-books that there are two kinds of zeros in mathematics,

the absolute algebraic zero arrived at as the difference of two equal numbers, *i.e.*,

$$a-a=0$$

and another kind arrived at, or rather never quite arrived at, as the limit of $1/a$ when a is increased indefinitely, *i.e.*,

$$\underset{a\to\infty}{lt.}\ 1/a=0\ ;$$

but the idea of a multiplicity of zeros has never seemed to the writer at all necessary or helpful. The limit in the above expression is the absolute algebraic zero, but it is important to remember that this limit is never actually reached.

Since

$$\underset{x\to\infty}{lt.}\ \frac{1}{x-1}=0$$

it follows that

$$\underset{x\to\infty}{lt.}\ 10^{\frac{1}{x-1}}=10^{0}=1$$

and that

$$\underset{x\to\infty}{lt.}\ 10^{\frac{1}{x-1}}+1=2$$

i.e.,

$$\underset{x\to\infty}{lt.}\ f(x)=2$$

Under these conditions the line representing the function is said to approach the line $y=2$ asymptotically, *i.e.*, it gets closer and closer to it as x is increased but never actually reaches it. It is tangential to it but the point of contact is at infinity.

In an exactly similar manner it can be shown that

$$\underset{x\to-\infty}{lt.}\ f(x)=2$$

so that we have for this function the four limiting conditions :—

$$\underset{x\to-\infty}{lt.}\ f(x)=2$$

$$\underset{x\to1-0}{lt.}\ f(x)=1$$

$$\underset{x\to1+0}{lt.}\ f(x)=\infty$$

$$\underset{x\to\infty}{lt.}\ f(x)=2$$

Now we come to a case which occurs very frequently in practical analysis and which might cause considerable perplexity to a person who had not assimilated the above ideas on limits. Take the function

$$y=F(x)=\frac{x^2+2x-3}{x^2+3x-4}$$

In general the value of this function for any value of the argument can easily be calculated by ordinary arithmetic, but when $x=1$ we have

$$y=F(1)=\frac{1+2-3}{1+3-4}=\frac{0}{0}$$

Now 0/0 is a group to which no meaning can be attached in terms of the fundamental conceptions of arithmetic. What then are we to do about this? In the first place, since the two quadratic expressions vanish when x is 1, it follows that each is divisible exactly by $(x-1)$ (see para. A5 of Section 6). With this clue it is easy to express the function in the form

$$F(x)=\frac{(x-1)(x+3)}{(x-1)(x+4)}$$

and now obviously we can divide the top and bottom of this fraction by $(x-1)$, so that

$$F(x)=\frac{(x+3)}{(x+4)}$$

and therefore when $x=1$

$$F(x)=\tfrac{4}{5}$$

All very plausible, isn't it—and quite wrong. It just shows how careful one has got to be. The top and bottom of the fraction can only be divided by $(x-1)$ on the condition that $(x-1)$ is *not* zero, *i.e.*, on the condition that x is *not* 1. Otherwise we are dividing top and bottom by zero, which, as we have seen, is definitely not legitimate under any circumstances whatever, so that just precisely the case in which it is essential to divide through by $(x-1)$ is the one in which it cannot be done. However, let us stop short just on the edge of the precipice, instead of falling over it, *i.e.*, put $x=1+h$ instead of 1, h being a small quantity compared with 1. Then

$$F(x)=F(1+h)=\frac{h(4+h)}{h(5+h)}$$

and since h is not zero

$$F(x)=F(1+h)=\frac{(4+h)}{(5+h)}$$

and this is true, however small h may be as

long as it is not zero. Now by making h small enough, the fraction can be made to differ from 4/5 by as little as we please. In other words, the limit of the fraction when x tends to 1 is 4/5. Therefore, although $F(x)$ has no defined value when x *is* 1, it has a definite limit when x *tends to* 1, that limit being 4/5, *i.e.*,

$$\underset{x \to 1}{lt.}\ F(x) = 4/5$$

Moreover, since the whole of the above reasoning can be repeated when $x=(1-h)$ with the same result, the limit is the same for either direction of approach, *i.e.*,

$$\underset{x \to 1 \pm 0}{lt.}\ F(x) = 4/5$$

What are we to say about the continuity of the function through this critical point? It is a difficult question to answer, and, as a matter of fact, the writer cannot give a definite answer himself and has not been able to get any authoritative general statement on the point. The difficulty is that the function certainly does not satisfy the continuity test at the point, since it has no defined value; nevertheless, it will be found that the function can be plotted as a perfectly smooth and apparently continuous line through this point, and moreover it satisfies the continuity definition if the *limit* when x tends to 1 be substituted in the definition for the *value* when $x=1$. Actually it is very unlikely that any error will arise in practice from assuming that this function, or any of the very large number of similar functions that are involved in practical mathematics, is continuous through this undefined and indeterminate point, but in the absence of any certainty in the matter any operations which involve the assumption of continuity will have to be carried through with some degree of mental reserve.*

So much for "continuity," "value," and "limit,"—or, at least, so much for an elementary introduction to these difficult but intriguing ideas. It may have seemed wordy and excessively fine drawn, but it is necessary all the same for, as Prof. Whitehead has pointed out, "large parts of mathematics as enunciated in the old happy-go-lucky manner were simply wrong." It is even probable, or at least possible, that the refinements of modern mathematics may prove insufficient in some directions. In any case, an excess of precision, if it is a fault at all, is a fault in the right direction, and is worth pursuing not only for its own sake but for the mental training it involves. There is no room for slipshod thinking in mathematics.

* This may seem unsatisfactory. It certainly is incomplete—but then, as the Philosopher says in *The Crock of Gold*, "Perfection is Finality. Finality is Death." It is part of the fascination of mathematics that it still leaves scope for research, and ever will do so, even within the limits of an elementary text-book.

Examples.—Continuity and Limits.

1. Show that the function

$$y = \frac{a + bx}{c + dx}$$

is discontinuous when $x = -c/d$. Find the limits of y when $x \to -(c/d) \pm 0$ and when $x \to \pm \infty$.

2. Find the points of discontinuity of

$$y = \frac{x^2 - 3x + 2}{x^2 - 7x + 12}$$

and find the limits of y when $x \to 3 \pm 0,\ 4 \pm 0, \pm \infty$.

3. Find the limits when $x \to a \pm 0$ of

$$y = \frac{x^2 - (a + b)x + ab}{x^2 - (a + c)x + ac}$$

4. Find the limits of

$$y = \frac{x^3 - 6x^2 + 11x - 6}{2x^3 - 14x + 28x - 8}$$

when $x \to 1 \pm 0,\ 2 \pm 0,\ 4 \pm 0$.

5. Find the limit when $x \to \infty$ of

$$y = \frac{ax^2 + bx + c}{mx^3 + nx^2 + px + q}$$

6. Find the limit of

$$\frac{\sqrt{x} - \sqrt{a} + \sqrt{x - a}}{\sqrt{x^2 - a^2}}$$

Answers to Examples in January Issue.

1. (a) $x = 3,\ y = 4,\ z = 5$. (b) $x = y = z = 1$. (c) $x = y = 0,\ z = 10$.
2. $w = 1,\ x = 2,\ y = 3,\ z = 4$.
3. $x = a + b,\ y = a + 2b,\ z = a + 3b$.
5. (a) 10. (b) 112/65.

Some New Coil Impedance Diagrams.

By W. A. Barclay, M.A.

In the present article the writer proposes to describe some results to which he has been led by the application of the method of Alignment to elementary wireless theory. As already stated in these pages, the Alignment Principle, a comparatively recent development of mathematics, is becoming more and more widely recognised as an instrument of singular efficacy and utility in the field of computation; while its beautiful generality and adaptability render it equally suited to the hardly less useful domain of geometrical illustration. The basic nature of the method—the alignment of certain points to which are attached numerical values of the variables represented—is fundamentally geometrical; and while the Principle itself is in essence a "shorthand" notation by which such alignments, where they exist, can be automatically detected, the results obtained by it can always be proved independently by the more cumbrous methods of ordinary analysis. In the sequel use will be made of elementary cartesian co-ordinate geometry to supply such "proofs" where necessary.

The interesting article on "Graphical Methods" by Mr. F. M. Colebrook (*E.W. & W.E.*, December, 1924) is doubtless still fresh in the minds of readers. In this article Mr. Colebrook described how, given a combination of resistance and reactance in parallel, a graphical process may be used to give the equivalent values of resistance and reactance which, if placed in series,

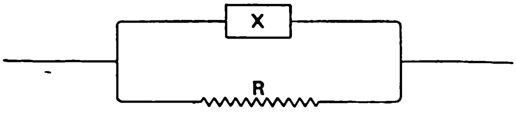


Fig. 1.

would give the same effective impedance at the working frequency. In so far as what follows is really an extension of Mr. Colebrook's method to the more general case of a reactance in parallel with an impedance, it may be well briefly to recapitulate his procedure. For the circuit of Fig. 1, where at a frequency of $\omega/2\pi$ we have a reactance X in parallel with a resistance R, we employ the construction of Fig. 2. Taking rectangular axes OX, OY, we set

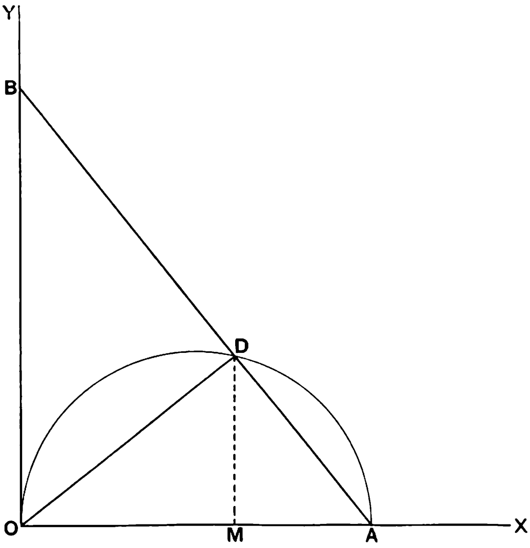


Fig. 2.

out on OX a length $OA=R$, and on OY a length $OB=X$. On OA describe a semicircle cutting AB in D. Draw DM perpendicular to OA. Then the effective resistance R_0 is represented by OM, the effective reactance X_0 by MD, and their vector combination, the effective impedance, by OD. The proof is simple, and readers are referred to the article in question for it.

We now proceed to consider the ubiquitous inductance coil and shunt tuning condenser of so many wireless circuits. We shall take R and L to represent the resistance and inductance of the coil, and C for the value of the shunting capacity. If an E.M.F. of frequency $\omega/2\pi$ is placed across the combination shown in Fig. 3, the numerical values of the reactances offered by the inductance and condenser are respectively ωL and $1/\omega C$. It should be stated at the outset that no account will here be

taken of the variation of H.F. resistance with frequency. This variation, of course, is of no importance at the lower frequencies. At radio frequencies, however, R will imply the H.F. resistance at the working frequency.

Apart altogether from considerations of H.F. resistance, the combination of inductance, capacity, and resistance of Fig. 3

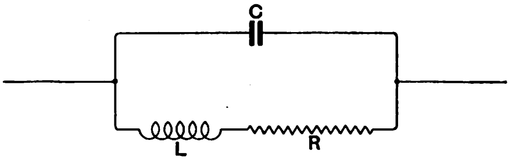


Fig. 3.

varies enormously in its behaviour at different frequencies. For example, we may consider the windings of an L.F. transformer, which have both inductance and self-capacity. Whereas at audio frequencies the inductance predominates, at radio frequencies the self-capacity exercises the greater effect, and the transformer behaves as a condenser. The question of finding equivalent series values for a combination of this nature is thus complicated by the fact that the effective reactance at the given frequency may be either inductive or capacitative. A ready means of determining its nature as well as its amount is, however, available, and is described below.

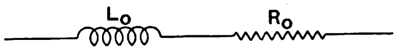


Fig. 4a.

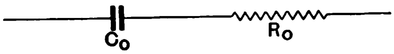


Fig. 4b.

Our problem is, then, to replace the circuit of Fig. 3 by either of those shown in Figs. 4a or 4b, in which the effective values L_0, R_0 or C_0, R_0 are to be found. As in any event the combination of Fig. 3 must be represented by one or other of Figs. 4a or 4b, we shall consider these two cases separately.

It may be shown that if a voltage $e=E\sin\omega t$ be impressed across the combination of Fig. 3, the total line current through the system is

$$i=E\left\{\frac{R}{R^2+\omega^2L^2}\sin\omega t-\left(\frac{\omega L}{R^2+\omega^2L^2}-\omega C\right)\cos\omega t\right\} \quad (1)$$

If now we impress the same voltage across the circuit of Fig 4a, we obtain for the line current,

$$i_0=E\left\{\frac{R_0}{R_0^2+\omega^2L_0^2}\sin\omega t-\frac{\omega L_0}{R_0^2+\omega^2L_0^2}\cos\omega t\right\} \quad (2a)$$

Equating those constituents of (1) and (2a) which are in the same phase relation, we find that for $i_0=i$ we must have,

$$\frac{R}{R^2+\omega^2L^2}=\frac{R_0}{R_0^2+\omega^2L_0^2}$$

and

$$\frac{\omega L}{R^2+\omega^2L^2}-\omega C=\frac{\omega L_0}{R_0^2+\omega^2L_0^2}$$

whence, solving for R_0 and ωL_0,

$$R_0=\frac{R}{(1-\omega^2CL)^2+\omega^2C^2R^2} \quad \ldots \quad (3a)$$

$$\omega L_0=\frac{\omega L(1-\omega^2CL)-\omega CR^2}{(1-\omega^2CL)^2+\omega^2C^2R^2} \quad \ldots \quad (4a)$$

Again, if the equivalent circuit is that of Fig. 4b, a voltage of $e=E\sin\omega t$ impressed on it will give a line current

$$i_0=E\left\{\frac{R_0}{R_0^2+\frac{1}{\omega^2C_0^2}}\sin\omega t+\frac{1/\omega C_0}{R_0^2+\frac{1}{\omega^2C_0^2}}\cos\omega t\right\} \quad (2b)$$

which, when compared with equation (1), yields

$$\frac{R}{R^2+\omega^2L^2}=\frac{R_0}{R_0^2+\frac{1}{\omega^2C_0^2}}$$

and

$$\frac{\omega L}{R^2+\omega^2L^2}-\omega C=-\frac{1/\omega C_0}{R_0^2+\frac{1}{\omega^2C_0^2}}$$

whence, solving for R_0 and $1/\omega C_0$,

$$R_0=\frac{R}{(1-\omega^2CL)^2+\omega^2C^2R^2} \quad \ldots \quad (3b)$$

$$-\frac{1}{\omega C_0}=\frac{\omega L(1-\omega^2CL)-\omega CR^2}{(1-\omega^2CL)^2+\omega^2C^2R^2} \quad \ldots \quad (4b)$$

By multiplying equations (4a) and (4b) throughout by ωC and adding unity, we obtain the expressions

$$1+\omega^2 CL = 1-\frac{C}{C_0}=\frac{1-\omega^2 CL}{(1-\omega^2 CL)^2+\omega^2 C^2 R^2}$$

from which, by using equations (3), we derive

$$\frac{R_0}{R}=\frac{1+\omega^2 CL_0}{1-\omega^2 CL}=\frac{\frac{1}{\omega C}+\omega L_0}{\frac{1}{\omega C}-\omega L} \quad \ldots \quad (5a)$$

and

$$\frac{R_0}{R}=\frac{1-\frac{C}{C_0}}{1-\omega^2 CL}=\frac{\frac{1}{\omega C}-\frac{1}{\omega C_0}}{\frac{1}{\omega C}-\omega L} \quad \ldots \quad (5b).$$

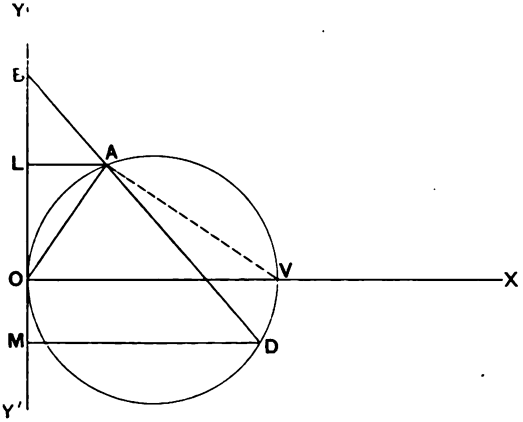


Fig. 5a.

Comparing equations (5a) and (5b) we find that

$$\omega L_0 = \frac{1}{\omega C_0}$$

an apparently anomalous result, which is explained by the fact that L_0 and C_0 cannot both exist simultaneously. The equations (5a) and (5b) are, of course, alternative; if a value of L_0 is found from (5a), the other equation (5b) is inoperative.

These equations (5a) and (5b) express in a convenient form the relations between R, C, L and R_0, C_0, L_0, and are, moreover, capable of a very simple geometrical interpretation as follows: In Figs. 5a, 5b, 5c, taking cartesian axes OX, OY, let the points A and B have co-ordinates $(R,\omega L)$ and $(O,1/\omega C)$. Then the point D whose co-ordinates are the effective values of resistance and reactance for the combination will be found in alignment with A

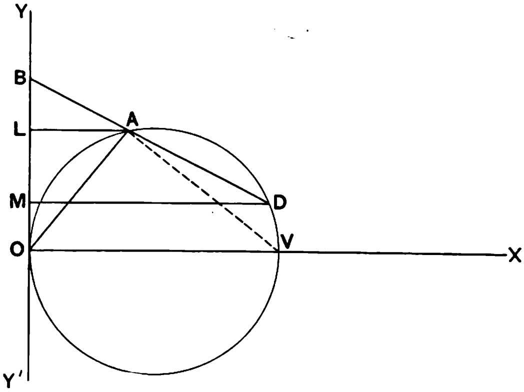


Fig. 5b.

and B. Moreover, if the effective reactance is inductive, D will be situated *beneath* OX, as in Fig. 5a; if capacitative, it will be *above* OX, as in Figs. 5b and 5c.

By drawing AL, DM, perpendicular to OY, we may easily verify these statements. In the similar triangles BMD, BLA,

$$\frac{MD}{LA}=\frac{MB}{LB}=\frac{OB-OM}{OB-OL} \quad \ldots \quad (6)$$

If, now, in Fig. 5a, OM is taken as $-\omega L_0$, while in Figs. 5b, 5c, it is taken as $1/\omega C_0$,

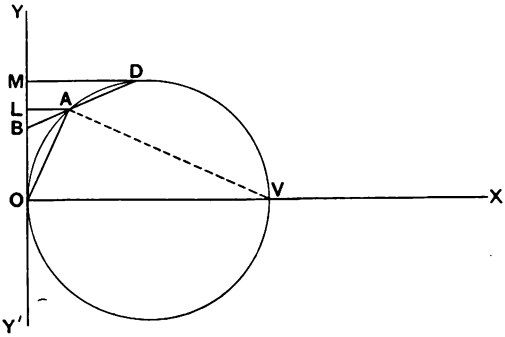


Fig. 5c.

and if $MD=R_0$ throughout, we find that the above equation is a geometrical interpretation of equations (5a) and (5b).

It will be noted that three possible cases arise. If $1/\omega C>\omega L$, the position of D

may be either above or below the axis OX, *i.e.*, the resulting effective reactance may be either inductive or capacitative, or indeed, zero should D happen to lie on OX. (See Figs. 5a and 5b.) If, however, $1/\omega C < \omega L$, the position of D will always lie above OX, and the effective reactance is in this case capacitative. (See Fig. 5c.)

It remains now to show how the position of the point D may be easily and rapidly determined. Draw AV perpendicular to OA to meet OX in V. On OV as diameter describe a circle which, since the angle OAV is right, will cut the line AB in A. The other point in which AB meets the circle is D, the required point of "effective" values, as may be shown as follows:—

Since OV is a diameter, OB is a tangent.

$$\therefore \quad BA \,.\, BD = BO^2$$

$$\therefore \quad BD = \frac{BO^2}{BA}$$

$$\text{Again,} \quad \frac{MD}{LA} = \frac{BD}{BA} = \frac{BO^2}{BA^2}$$

$$\therefore \quad MD = LA \,.\, \frac{BO^2}{BA^2} = \frac{R \,.\, \dfrac{1}{\omega^2 C^2}}{\left(\dfrac{1}{\omega C} - \omega L\right)^2 + R^2}$$

$$= \frac{R}{(1-\omega^2 CL)^2 + \omega^2 C^2 R^2} \qquad (7)$$

$$= R_0, \text{ by equation (3a).}$$

D is thus the point on AB whose x-coordinate is R_0. Hence D is the required point.

We are now in a position to study at first hand, and without the necessity for tedious algebraical analysis, the numerical effect upon R_0, ωL_0, $1/\omega C_0$, of changes in the value of $1/\omega C$ due to variation of capacity in shunt with any given coil. For the frequency $\omega/2\pi$, we can plot the position of the point A the co-ordinates of which $(R, \omega L)$ represent its resistance and reactance at this frequency. Further, by means of the construction given, we can always draw the circle which represents the locus of the possible "effective" points D. From this construction it will be seen that the dimensions of this circle depend solely on the constants of the coil, and are quite independent of the tuning capacity. The particular "effective" point corresponding to any given shunt capacity is found in alignment with A and the value of such shunt capacitative reactance taken on the axis of Y. It is to be noted that the distinction between the reactances represented by D, according as this point is situated in the upper or lower quadrants XOY, XOY' holds only for "effective" reactance values. The reactances of the constituents of the given combination are always set out in the upper quadrant XOY.

As the shunt capacity across the coil is varied, the point B representing its reactance $1/\omega C$ will move along the axis OY, while the point D travels along the circle. In particular, when D reaches the axis OX,

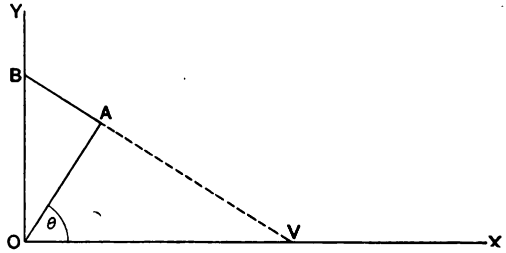


Fig. 6.

it coincides with V. The effective reactance is now zero, the circuit is said to be "tuned" to the working frequency, and its effective resistance R_0 is seen to be a maximum and equal to the diameter of the circle OV. From this circumstance arises a simple construction for obtaining the capacitative reactance necessary to tune a coil to a given frequency. (See Fig. 6.) If through A, the point $(R, L\omega)$, be drawn a line AB perpendicular to OA to meet the Y-axis in B, the distance OB will represent the shunt capacitative reactance $1/\omega C$ to obtain resonance. The numerical value of R_0 at resonance is obtained by putting ωL_0 or $1/\omega C_0 = 0$ in equations (5a) or (5b). We then have,

$$\frac{R_0}{R} = \frac{1}{1-\omega^2 CL} \qquad \dots \quad (8)$$

The denominator of this fraction is not, of course, zero. To obtain resonance in the circuit of Fig. 3, the capacitative reactance of the condenser must be greater than the inductive reactance of the coil. This is shown by the gradient of the line AB,

which, in order that D coincide with V, must be negative, *i.e.*,

$$\frac{1}{\omega C} > \omega L$$

For the resonant condition, also, the numerators of equations (4) will vanish, so that we have

$$\omega L(1 - \omega^2 CL) = \omega CR^2 \quad \dots \quad (9)$$

i.e.,
$$\frac{1}{\omega C} = \omega L + \frac{R^2}{\omega L} \quad \dots \quad (10)$$

and eliminating ωC by means of (8), taking angle $AOX = \theta$,

$$R_0 = R\left(1 + \frac{\omega^2 L^2}{R^2}\right) = R\,sec^2\theta \qquad (11)$$

Equation (11) is a convenient expression for the maximum effective resistance which obtains at resonance, and gives, moreover, the diameter of the circle of our construction. It thus appears that a line drawn through A perpendicular to OA intercepts on the axes OX and OY lengths equal respectively to the effective resistance at resonance, and the necessary shunt capacitative reactance to produce resonance.

From equation (10) we can determine numerically what is otherwise evident geometrically, whether the effective reactance of the coil is inductive or capacitative, the equation itself being the condition for zero reactance. From equations (4a) and (4b) we see that if

$$\omega L(1 - \omega^2 CL) > \omega CR^2$$

i.e., if
$$\frac{1}{\omega C} > \omega L + \frac{R^2}{\omega L} \quad \dots \quad (12)$$

the effective reactance is inductive (Fig. 5a), while if

$$\frac{1}{\omega C} < \omega L + \frac{R^2}{\omega L} \quad \dots \quad (13)$$

the effective reactance is capacitative (Figs. 5b and 5c). In all cases the effective values are read as the co-ordinates of D. From (13) it is obvious *a fortiori* that if

$$\frac{1}{\omega C} < \omega L$$

the effective reactance is always capacitative. If, however,

$$\frac{1}{\omega C} > \omega L$$

the graphical construction provides a simple means of determining the nature as well as the magnitude of the effective values.

Many other interesting relations between R, ωL, $1/\omega C$, and the effective values R_0, ωL_0, or R_0, $1/\omega C_0$, may be derived at sight from the diagrams. For example, the points A and B may be so situated that D coincides with A. (See Fig. 7.) In this case the line AB is a tangent to the circle at A; the effective resistance is equal to the resistance of the coil, while the effective reactance is equal in amount to the inductive reactance of the coil, but is capacitative in character. If the tuning capacity be now increased, B approaches O, and D will travel along the arc from A towards O. The effective resistance decreases, while the changes in the effective reactance may

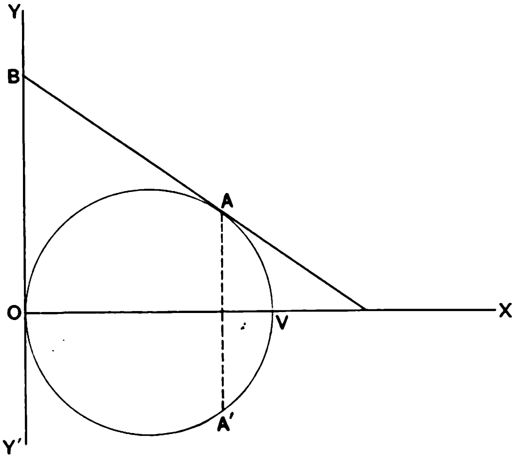


Fig. 7.

be traced on the diagram. On the other hand, as the shunt capacity is decreased, the point D travels through the resonance point V, and finally approaches a limiting position A', the image of A in OX. At this point, of course, the effective values of the combination are simply those of the unshunted coil itself, the point B being at infinity.

Again, the line AB may be parallel to OX. This indicates, it will be seen, that the inductive reactance of the coil, the shunt reactance of the condenser, and the effective reactance of the combination are all numerically equal, the latter being necessarily capacitative. (See Fig. 8.) From the properties of the circle, it will also be observed

that the square of this magnitude is equal to the product of the resistance of the coil and the effective resistance of the combination.

Further, we may revert to the case discussed by Mr. Colebrook to which reference

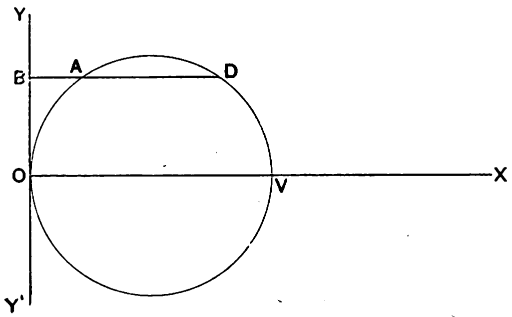


Fig. 8.

was made at the outset. Our coil is here replaced by a pure resistance, shunted as usual by a capacity. The point A is now situated on OX, and the necessary circle described upon OA as diameter, the effective point D being obtained by intersection with AB. The procedure shown in Fig 2 is thus a particular case of the present method.

In conclusion, it may be said that the present discussion is limited entirely to the case of the coil, with shunt condenser. The method described is, however, capable of considerable extension, and is likely to be of much practical value in dealing with various combinations of impedances.

It should be mentioned that since the co-ordinates of D above represent the effective resistance and reactance of the coil and shunt condenser in both magnitude and direction, the line OD may be regarded as their vector resultant, and represents in magnitude and phase the effective impedance of the combination. It should be carefully noted, however, that the lines OA and OB for the constituents of the original combination cannot thus be vectorially combined. The reactances represented by A and B are 180° out of phase, so that to be treated as vectors they would require to be shown in opposite quadrants and not, as in these diagrams, in similar phase relationship.

Book Received.

THE WAY TO TRUE RADIO REPRODUCTION.—A 24-page pamphlet issued by Messrs. Ferranti, price 1s. Diagrams are given of a number of receiving sets with numerical data of the various components. Hints are given as to the choice of valves, the effect of wrong anode and grid voltages on the quality of reproduction, the dangers of overloading the last valve or the loud-speaker and, of course, the danger of using any but a Ferranti transformer. Useful tables of valve characteristics add to the usefulness of the pamphlet.

Catalogue Received.

The Great Northern Telegraph Co., Ltd., Copenhagen (5, St. Helens Place, London, E.C.3). This Company possesses a factory for the manufacture of electrical instruments. The Catalogue covers the whole range of telegraph apparatus and instruments such as galvanometers, Wheatstone bridges, standard condensers, etc., used in connection with telegraphic work. The Catalogue is beautifully illustrated with photographic reproductions of the various instruments.

Valve Nomenclature and Standardisation.

The Telefunken Company announce that in future the type-numbers given to their valves will not be mere arbitrary numbers but will indicate the filament voltage and current. The first two of the three figures give the current in hundredths of an ampere, whilst the third gives the approximate voltage for which the valve is suitable. The letters which precede the number indicate the application for which the valve is designed ; thus RE064 is a receiving valve (Röhre=valve ; Empfänger=receiver) taking 0.06 ampere at 4 volts. They also announce that they are giving up the special Telefunken socket and adopting the standard European socket for their valves.

Unipivot Galvanometers.

From the Cambridge Instrument Co., Ltd., 45, Grosvenor Place, London, S.W.1, we have received an interesting brochure (list No. 160) describing Unipivot instruments for D.C. measurements. The list deals chiefly with the well-known Unipivot Galvanometers and other accessories, which have proved of considerable usefulness in scientific and industrial work ever since the introduction of the Unipivot principle in 1903.

The essential feature of this design is that the moving coil is supported on one pivot only ; this results in a diminution of pivot friction. A further advantage of the design is that it is unnecessary to level the instruments which are thus particularly suitable for installation on board ship and moving vehicles.

Simple Resonance Curves and their Modification by Valve Circuits.

By Prof. E. Mallett, D.Sc., M.I.E.E.

Introduction.

IN the present article a vector treatment of simple resonance curves is described, by means of which the resonance curves in cases where there is only one tuned circuit, which may be associated with a valve with or without reaction, may be predicted, or by which, if the resonance curve is obtained experimentally by varying the frequency, the effective decay factor of the circuit can be found. Incidentally the conditions for maintenance of oscillations by a valve, when the oscillatory circuit is connected either to the grid or to the anode, are arrived at.

Contents.

1. Series impedance—resonance curves and circles—circle and straight line instruction to find decay factor.
2. Parallel resonance—valve amplifier with tuned anode—conditions for oscillation—the anode tap.
3. Oscillatory circuit connected to grid —conditions for oscillations.

1. If a constant electromotive force e is introduced into an oscillatory circuit

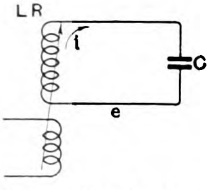


Fig. 1. *An electromotive force* e *induced into a simple oscillatory circuit as above, produces a current* i *such that*

$$i = \frac{e}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} = \frac{e}{Z}$$

having inductance L, capacity C, and total high frequency resistance R (Fig. 1), the magnitude of the current i is given by the expression

$$i = \frac{e}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} \quad .. \quad (1a)$$

and its phase angle ϕ with regard to that of e which is regarded as standard is given by

$$\tan\phi = -\frac{\omega L - \frac{1}{\omega C}}{R} \quad .. \quad (1b)$$

Both of these expressions are contained in the one statement

$$\left.\begin{aligned} i &= \frac{e}{R + j\left(\omega L - \frac{1}{\omega C}\right)} \quad .. \\ \text{or} \quad i &= \frac{e}{Z} \quad .. \quad .. \quad .. \end{aligned}\right\} (2)$$

where $Z = R + j\left(\omega L - \frac{1}{\omega C}\right)$ is the complex impedance of the oscillatory circuit, and is drawn as shown in Fig. 2. Or $= R$ is drawn horizontally to the right and $rP = \left(\omega L - \frac{1}{\omega C}\right)$ is drawn vertically from r, since $\left(\omega L - \frac{1}{\omega C}\right)$ is multiplied by j in equation (2), meaning

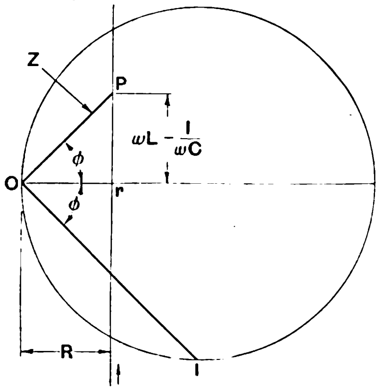


Fig. 2. *Showing how the complex impedance* Z *of the oscillatory circuit is composed of the resistance* R *with the reactance* (ωL — 1/ωC) *added at right angles. Since the current* i *in the circuit varies as the reciprocal of the impedance, it must be represented as such in the diagram.* OP *represents the impedance and* OI *the current in the circuit, and the locus of the point* I, *as the frequency* ω/2π *of the induced E.M.F. varies, is the circle shown.*

that the length $\left(\omega L - \frac{1}{\omega C}\right)$ is rotated through 90° counter clockwise from the horizontal.

Complex expressions such as

$$R + j\left(\omega L - \frac{1}{\omega C}\right)$$

can be dealt with algebraically in exactly the same way as any other expressions, the meaning to be ascribed to j being $\sqrt{-1}$. Thus

$$j^2 = -1,\ j^3 = j^2,\ j = -1\sqrt{-1} = -j.$$

Geometrically multiplication by j^2 indicates rotation through 90° twice, or rotation through 180°, and by j^3 rotation through 270°, which brings us to the same position as multiplication by $-j$, or rotation in the negative direction, *i.e.*, clockwise through 90°.

Now, in Fig. 2 we could also have drawn the complex OP by drawing a line at an angle ϕ and marking along it a length $OP = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2} = |Z|$, the verticals indicating that the numberical size of the complex Z is intended and not the actual complex. The angle ϕ is obviously determined by $\tan\phi = \dfrac{\omega L - \frac{1}{\omega C}}{R}$.

So we have two ways of writing Z, either $|Z| \underline{/\phi}$ or $R + j\left(\omega L - \frac{1}{\omega C}\right)$, and we can easily change from one way to the other, as above if R and $\left(\omega L - \frac{1}{\omega C}\right)$ are known, and by

$$R = |Z| \cos\phi \text{ and } \left(\omega L - \frac{1}{\omega C}\right) = |Z| \sin\phi$$

if $|Z|$ and ϕ are known.

The algebra of multiplying or dividing is simplified by converting complexes to the form $|Z| \underline{/\phi}$, for then $|Z_1| \underline{/\phi_1} \times |Z_2| \underline{/\phi_2}$

$$= |Z_1| \times |Z_2| \underline{/\phi_1 + \phi_2}$$

and

$$\frac{|Z_1| \underline{/\phi_1}}{|Z_2| \underline{/\phi_2}} = \frac{|Z_1|}{|Z_2|} \underline{/\phi_1 - \phi_2}$$

and so on. For adding and subtracting the form $R + jX$ is best, when $(R_1 + jX_1) + (R_2 + jX_2) + = (R_1 + R_2) + j(X_1 + X_2)$, etc., *i.e.*, the terms without j (called the real terms) and those with j (called the imaginary terms) are added separately.

As a special case of dividing we have the reciprocal

$$\frac{1}{|Z| \underline{/\phi}} = \frac{1}{|Z|} \underline{/-\phi}$$

which is often written

$$\frac{1}{|Z|} \overline{\backslash\phi},$$

the inverted angle sign indicating that the angle is to be multiplied by —1.

In equation (2) $i = e/Z$, therefore, to find the vector i, e being considered of standard phase, *i.e.*, having a zero angle, we have

$$i = \frac{e}{|Z| \underline{/\phi}} = \frac{e}{|Z|} \underline{/-\phi},$$

or we draw OI at an angle ϕ below the horizontal and of length $e/|Z|$, or if we draw it equal to $1/|Z|$, it represents the current in the oscillatory circuit per volt of electromotive force applied.

It is evident that the position of P, and therefore of I, depends upon the value of ω. Assuming that the resistance R remains constant, P will evidently lie always upon the vertical line through r. When ω is very small $(\omega L - 1/\omega C)$ has a large negative value, and P is at a great distance below r. When ω is very large $(\omega L - 1/\omega C)$ has a large positive value and P is a great distance above r. When ω is such that

$$\omega L - \frac{1}{\omega C} = O \left(\text{or } \omega = \frac{1}{\sqrt{LC}}\right)$$

P coincides with r. As ω increases, therefore, from a small value P starting from a great distance below r travels upwards through r. This is indicated by the arrow.

Now let us trace the corresponding changes of the point I. When P is far below r the angle rOP will be nearly 90°, so that the angle of I (rOI) will be nearly 90° drawn upwards, and the length OI, which is equal to $1/OP$, will be very small. Thus I, when ω is very small, is very near O but almost vertically above it. As P moves upwards to r, the angle of OI will decrease from 90° to 0, while its length will increase from 0 to its maximum value $=1/R$. With P moving above r, *i.e.*, with positive angle, I will have a negative angle increasing to 90°, while the length of OI will decrease to 0. I will in fact move round a circle with diameter $1/R$ in a clockwise direction starting from 0 as ω is increased from a very small value.

That the locus of I is a circle is seen from the fact that

$$OI = \frac{1}{Z} = \frac{1}{R} \cos \phi,$$

which is the equation of a circle of diameter $1/R$ in polar co-ordinates.

If now in the circuit of Fig. 1 we measure

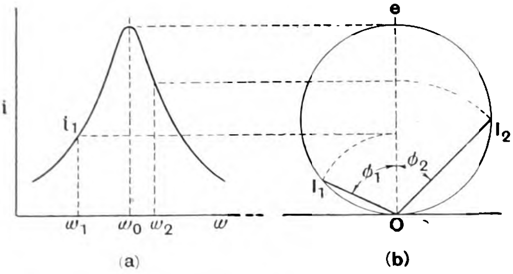


Fig. 3. *Showing* (a) *how the current in the circuit alters as the frequency $\omega/2\pi$ of the induced E.M.F. is varied : and* (b) *how the current may be represented by chords of a circle.*

the current i for various values of ω we obtain the well-known resonance curve of Fig. 3(a). We have measured only the magnitude of the current which is generally only half the story in an alternating current circuit. We cannot measure the phase angles. But from our resonance curve, knowing that it is to be derived from a circle, we can work backwards and find the phase angles graphically. The diameter of the circle is the maximum value of the current, so the circle is drawn accordingly at b (Fig. 3). At the maximum value (at ω_0) the current and volts are in phase, so the electromotive force vector is drawn along the diameter Oe. At any other ω value ω_1 a vertical is drawn to meet the resonance curve in i_1, a horizontal is drawn through i_1 to meet Oe in 1, and with centre O and radius $O1$ an arc is drawn to meet the circle in I_1. Then OI_1 is the current vector for the frequency corresponding to ω_1, and its phase angle is $eOI_1 = \phi_1$. At an angular frequency ω_2 past the resonance value the current vector found in the same way is OI_2, and the angle ϕ_2 is negative. Thus for any value of ω we can find the corresponding value of ϕ.

Now in the case of the sharp resonances met with in wireless work there is a very simple relation between ω and ϕ.

We have seen (1(b) or Fig. 2) that

$$\tan \phi = - \frac{\omega L - \dfrac{1}{\omega C}}{R}$$

Differentiating with respect to ω we have

$$\frac{d \tan \phi}{d\omega} = -\left(\frac{L}{R} + \frac{1}{\omega^2 CR}\right)$$

$$= -\frac{L}{R}\left(1 + \frac{1}{\omega^2 CL}\right) = -\frac{L}{R}\left(1 + \frac{\omega_0^2}{\omega^2}\right)$$

Now, when the resonance is very sharp most of the circle is described with only a small change of ω, so that ω is always very nearly ω_0 and ω_0^2/ω^2 very nearly one. And then

$$\frac{d \tan \phi}{d\omega} = -\frac{2L}{R} \quad \text{or} \quad \frac{d\omega}{d \tan \phi} = -\frac{R}{2L}$$

$$= -a \quad \dots (3)$$

where $a = R/2L =$ the decay factor of the circuit. Even when the resonance is not sharp this holds for the resonance value.

If, therefore, we plot a curve of ω against $\tan \phi$, this curve will be practically a straight line, whose slope will give us the decay factor of the circuit.

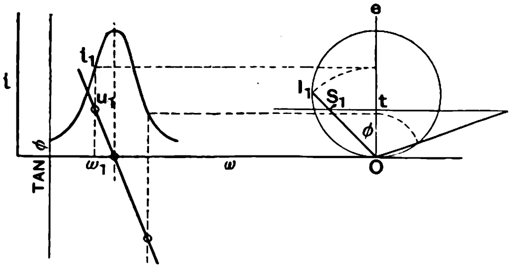


Fig. 4. *Showing how to obtain the decay factor* R/2L *of an oscillatory circuit from its resonance curve. The slope of the line showing the relation between* tan ϕ $\left(\textit{which equals} -\frac{\omega L - 1/\omega C}{R}\right)$ *and* ω *gives the decay factor.*

The easiest way to draw this curve of $\omega/\tan \phi$ is indicated in Fig. 4. On the circle diagram a length Ot is measured along Oe equal to one, to any convenient scale, and the current vector OI, cuts the horizontal through t in S_1. Then since $\tan \phi = St/Ot = St$ to the same scale that makes $Ot = 1$, the length St set up vertically at ω_1, on the resonance curve diagram gives a point μ_1 on the curve of ω against $\tan \phi$.

Generally it is not possible in a wireless

circuit to measure i directly without introducing the resistance, which is probably considerable, of an ammeter, but the same information can be obtained by measuring the voltage across the condenser. If this is done with a valve voltmeter with sufficient negative grid bias, the circuit constants are not appreciably affected and the volts read are sufficiently nearly directly proportional to the current.

Further, if instead of varying the frequency of the supply, the condenser of the

Now

$$\omega_0 = \frac{1}{\sqrt{L}} \times \frac{1}{\sqrt{C}} = \frac{1}{\sqrt{5{,}000 \times 10^{-6}}} \times \frac{10^6}{\sqrt{C}}$$

$$= 14.1 \times 10^6 \times \frac{1}{\sqrt{C}}$$

$$\therefore \frac{d\omega_0}{d \tan \phi} = a = .0008 \times 14.1 \times 10^6 = 11{,}300$$

and $R = a \times 2L = 11{,}300 \times 2 \times 5{,}000 \times 10^{-6}$
$= 113$ ohms.

A small decay factor means not only a

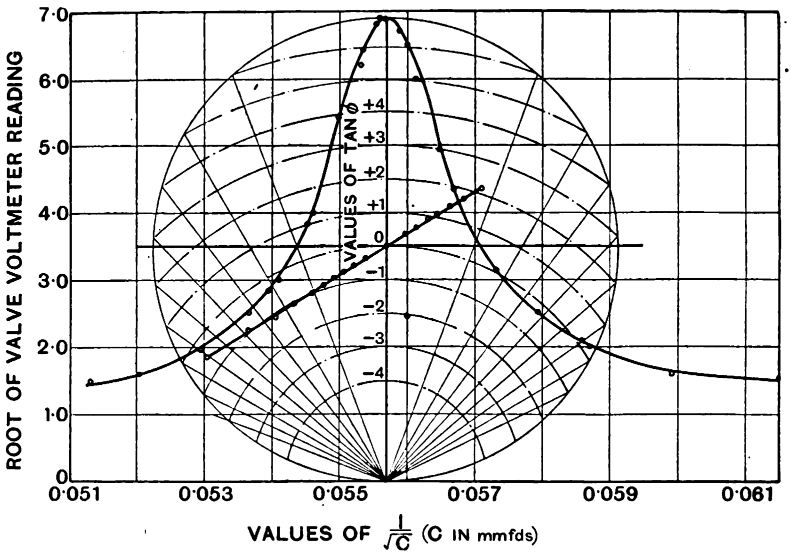


Fig. 5. *Actual determination of the decay factor from an experimentally obtained resonance curve.*

oscillatory circuit is varied, the same considerations as above apply if $\omega_0 = 1/\sqrt{LC}$ takes the place of ω. Fig. 5 gives an experimentally obtained resonance curve showing the root of the valve voltmeter reading (*i.e.*, figures proportional to the volts) across the condenser plotted against the $1/\sqrt{C}$, which is proportional to the value of ω_0. The inductance of the circuit was 5,000μH and the angular frequency of the supply 7.87×10^6.

From the construction carried out on the curve we have for the slope of the line

$$\frac{d\,\frac{1}{\sqrt{C}}}{d \tan \phi} = \frac{.0032}{4} = .0008 \ (C \text{ in } \mu\mu\text{F}).$$

larger voltage available at the resonant frequency, but what is of even greater importance in these days of an already crowded ether, greater selectivity, that is a greater ratio of the current in the circuit at the resonant frequency to that with the same applied volts at any other frequency. The circle, besides having a larger diameter, is described with a smaller change of ω.

A standard resonance curve applicable to any simple circuit can be drawn as in Fig. 6. We have

$$i = \frac{e}{R + j\left(\omega L - \frac{1}{\omega C}\right)}$$

Now $\left(\omega L - \frac{1}{\omega C}\right) = \omega L \left(1 - \frac{1}{\omega^2 LC}\right)$

and since $\omega_0{}^2 = \frac{1}{LC}$

$$\left(\omega L - \frac{1}{\omega C}\right) = \omega L\left(1 - \frac{\omega_0{}^2}{\omega^2}\right)$$
$$= \omega L\left(1 - \frac{\omega_0}{\omega}\right)\left(1 + \frac{\omega_0}{\omega}\right)$$
$$= 2L\ (\omega - \omega_0),$$

since ω_0/ω is very nearly 1 in all wireless applications.

So we may write

$$i = \frac{e}{R + j2L\,(\omega - \omega_0)}$$

and since at resonance $i_R = \frac{e}{R}$

$$\frac{i}{i_R} = \frac{1}{1 + j\frac{2L}{R}(\omega - \omega_0)} = \frac{1}{1 + j.\frac{\omega - \omega_0}{a}}, \quad (4)$$

Take $OA = 1$ in. $= 1$ and mark vertically along AB various points to represent $\omega - \omega_0/a$ to the same scale. Then rays such as OC are

$$\left(1 + j\,\frac{\omega - \omega_0}{a}\right),$$

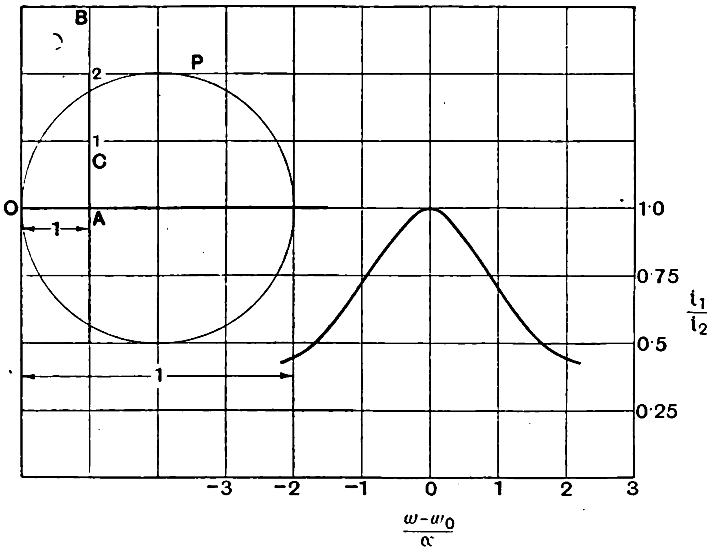


Fig. 6. *A standard resonance curve which is applicable to any simple circuit, in which* $w_0 = \frac{1}{\sqrt{LC}}$ *and* $a = R/2L$ *as before.*

and these continued to cut a circle drawn along OA as diameter to some suitable scale (in this case 4 in. $= 1$) give the values of i/i_R as OP. OP is plotted against $\omega - \omega_0/a$ on the right of the figure.

To convert the abscissæ to ω we must multiply by a and the greater a the greater the frequency change before the ratio i/i_R is reduced to a half, say. For instance, if $a = 1{,}000$, 1 in. of the abscissa represents 1,000 in the ω scale, and the current is halved if ω is off resonance by 1,700. But if $a = 5{,}000$, 1 in. $=$ 5,000 ω and a change in ω of 8,500 is required to halve the current. In the case of parallel resonance (Fig. 7) the voltage across the parallel inductance and condenser follows the same law as the current in the series resonance case. For the parallel impedance Z_p we have

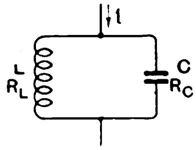


Fig. 7. *A simple parallel resonance circuit.*

$$Z_p = \frac{\left(R_L + j\omega L\right)\left(R_c - \frac{j}{\omega C}\right)}{R_L + j\omega L + R_c - \frac{j}{\omega C}}$$

where R_L and R_c are the resistances of the inductance and condenser respectively.

Writing $Z = R_L + R_c + j\omega L - j/\omega C =$ the series impedance round the oscillatory circuit, and neglecting in the numerator R_L

in comparison with $j\omega L$, and R_c in comparison with $-j/\omega C$, we have

$$Z_p = \frac{L}{CZ} \quad .. \quad .. \quad (5)$$

If we have a constant current i, reckoned of standard phase, through the circuit, the voltage across the circuit is

$$Z_p i = \frac{L}{CZ}\, i = \frac{1}{Z} \times \frac{Li}{C},$$

which is of the same form exactly as the current in the series case with constant e. The locus is a circle therefore, and the curve of volts/ω a simple resonance curve with decay factor $R/2L$, where R is the total series resistance $= R_L + R_c$.

The chief wireless interest of such a parallel circuit is in its use in the tuned anode scheme of Fig. 8.

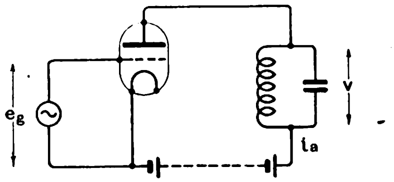


Fig. 8. *Showing the use of a parallel resonance circuit in the anode circuit of a valve.*

We have a voltage e_g applied to the grid resulting in an anode current i_a given by

$$i_a = \frac{\mu e_g}{R_a + Z_p}$$

where R_a is the internal resistance (anode-filament) of the valve and μ its amplification factor. The voltage v available across the tuned circuit is

$$\begin{aligned} v &= i_a Z_p \\ &= \frac{\mu e_g Z_p}{R_a + Z_p} \\ &= \mu e_g \frac{1}{\frac{R_a}{Z_p} + 1} = \mu e_g \frac{1}{\frac{R_a C Z}{L} + 1} \end{aligned} \quad (6)$$

The voltage amplification is

$$\frac{v}{e_g} = \frac{\mu}{\frac{R_a C Z}{L} + 1} \quad .. \quad (7)$$

which at the resonant frequency is

$$\frac{\mu}{\frac{C}{L} \cdot RR_a + 1}.$$

In a typical case of a well-designed circuit, say $C = 1{,}000\mu\mu$F, $L = 4{,}000\mu$H, $R = 10$ ohms and $R_a = 25{,}000$ ohms,

$$\frac{C}{L} RR_a = .06$$

and the voltage amplification is $\mu/1.06$, within 6 per cent. of the maximum μ obtainable in this way.

Going back to equation (6) we may write

$$v = \mu e_g \cdot \frac{\frac{L}{R_a C}}{Z + \frac{L}{R_a C}} \quad .. \quad (8)$$

$$= \frac{\frac{\mu L}{R_a C}}{R + \frac{L}{R_a C} + j\left(\omega L - \frac{1}{\omega C}\right)} e_g \quad (9)$$

In this expression the numerator is a constant, and the only j term in the denominator is

$$j\left(\omega L - \frac{1}{\omega C}\right).$$

Resonance occurs therefore as before when

$$\omega^2 = \frac{1}{LC},$$

and the form of vector diagram and of the resonance curve is the same as in the simple oscillatory circuit. The effective decay factor has, however, been increased by the addition of the term L/R_aC to the resistance in the denominator. R has in fact been replaced by

$$\left(R + \frac{L}{R_a C}\right),$$

so that the decay factor is now

$$\frac{R + \frac{L}{R_a C}}{2L} = \frac{R}{2L} + \frac{1}{2R_a C} \quad (10)$$

In the original circuit the decay factor was

$$\frac{R}{2L} = \frac{10}{2 \times 4{,}000 \times 10^{-6}} = 1{,}200$$

Now

$$\frac{1}{2R_a C} = \frac{1}{2 \times 25{,}000 \times 1{,}000 \times 10^{-12}} = 20{,}000.$$

So that the effective decay factor is now 21,200, nearly 20 times its original value. and our selectivity is very seriously reduced,

This is where reaction comes in. By reacting back to the grid circuit we can

reduce the effective resistance and decay factor without any limit except that imposed by stability. This will give a very material increase in voltage amplification available, and at the same time will greatly increase the selectivity.

Consider the case of back coupling by mutual induction M from the anode coil to the grid coil. The current in the anode coil is very nearly

$$\frac{j\omega L}{Z} i_a,$$

so that the additional grid voltage produced by the mutual inductance is

$$j\omega M \times \frac{j\omega L}{Z} i_a = -\frac{\omega^2 ML}{Z} i_a.$$

The total grid voltage is therefore

$$v_g = e_g - \frac{\omega^2 ML}{Z} i_a,$$

or if we turn the coil so that M is such as to increase the grid voltage (the sign of M can be made $+^{ve}$ or $-^{ve}$ at will), we may write

$$v_g = e_g + \frac{\omega^2 ML}{Z} i_a,$$

and

$$i_a = \frac{\mu v_g}{R_a + Z_p} = \frac{\mu\left(e_g + \frac{\omega^2 ML}{Z} i_a\right)}{R_a + Z_p}$$

so that

$$i_a \left(1 - \frac{\frac{\mu\omega^2 ML}{Z}}{R_a + Z_p}\right) = \frac{\mu e_g}{R_a + Z_p}$$

$$i_a = \frac{\mu e_g}{R_a + Z_p - \frac{\mu\omega^2 ML}{Z}} \quad .. \quad (11)$$

and the voltage v available $= i_a Z_p = i_a \frac{L}{CZ}$ is

$$v = \frac{\mu e_g}{\frac{R_a CZ}{L} + 1 - \mu\omega^2 MC} = \frac{\mu e_g}{\frac{R_a CZ}{L} + 1 - \frac{\mu M}{L}} \quad (12)$$

We note in passing that this is infinity when the denominator is 0. This is evidently the condition for self-oscillation to start, *i.e.*,

$$\frac{R_a CZ}{L} + 1 - \frac{\mu M}{L} = 0$$

or, since the oscillations will be at resonance, very nearly, when $Z = R$,

$$M = \frac{1}{\mu}(R_a RC + L) \quad .. \quad (13)$$

It is clear therefore that placing the oscillatory circuit in the anode of a valve increases its effective damping very considerably, but that this increase may be wiped off by reaction. In the case considered the effective decay factor of 1,200 is increased to 21,200 by the valve, and the greater part of the damping to be wiped off is due to the valve itself. One may well ask therefore why the great demand for "low loss" coils and condensers! The resistance of the circuit can be doubled or even quadrupled without any great effect in its use as a tuned anode.

The less the reaction that is required the more stable will be the adjustment of the circuit. In order therefore to use the tuned anode circuit with high efficiency coils and condensers to the best advantage it is necessary to adopt some scheme in which the

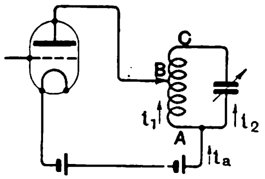


Fig. 9. *Illustrating the use of the "anode tap" in receiving circuits in order to reduce the damping of the oscillatory circuit due to the valve itself.*

effective resistance introduced by the valve itself is reduced. This can be done by including only a portion of the inductance in the anode circuit, as indicated in Fig. 9, which is the same arrangement as the "anode tap" used in oscillating circuits. For the idea of using this arrangement in receiving circuits the author is indebted to Prof. C. L. Fortescue.*

Let us suppose that the tap B is placed so that when a current is flowing through the inductance the voltage across AB is b times the voltage across AC. Then neglecting the resistance of the coil and assuming further that the currents i in AB and BC are equal, we know that the effective impedance of $AB = b \times$ impedance of AC; the parallel impedance introduced into the anode circuit is,

$$Z_p = \frac{(\text{Effec. Imped. } AB)\ (\text{Effec. Imped. } BCA)}{\text{Total series impedance.}} \quad (14)$$

* C. L. Fortescue, *Engineering*, 10th Oct., 1919, p. 491, and *Journal of the Radio Society of Gt. Britain*, Vol. VI., p. 15.

$$= \frac{j\omega Lb\left\{(1-b)(j\omega L) - \frac{j}{\omega C}\right\}}{Z}$$

$$= \frac{(j\omega Lb)(-j\omega Lb)}{Z} = b^2\frac{L}{CZ} \quad .. \quad (15)$$

Working this out more in detail, let $r_1 l_1$, $r_2 l_2$ be the resistance and inductance of AB and BCA respectively (r_2 includes the condenser resistance) and m the mutual inductance between the coils. Let i_a, i_1 and i_2 be the anode current, and the currents through AB and ACB in order, and v the voltage across AB.

Then

$$i_a = i_1 + i_2$$

$$v = i_1(r_1 + j\omega l_1) - j\omega m i_2$$

$$= i_2\left(r_2 + j\omega l_2 - \frac{j}{\omega C}\right) - j\omega m i_1$$

Whence

$$i_1(r_1 + j\omega l_1 + j\omega m) = i_2\left(r_2 + j\omega l_2 - \frac{j}{\omega C} + j\omega m\right)$$

Write $z_1 = (r_1 + j\omega l_1 + j\omega m)$

$$z_2 = \left(r_2 + j\omega l_2 - \frac{j}{\omega C} + j\omega m\right)$$

Then

$$i_1 z_1 = i_2 z_2 \text{ and } i_1 = i_a - i_2 = i_a - \frac{z_1}{z_2} i_1$$

$$\therefore \quad i_1 = \frac{i_a}{1 + \frac{z_1}{z_2}} \qquad i_2 = \frac{i_a}{1 + \frac{z_2}{z_1}}$$

Now $v = i_1(r_1 + j\omega l_1) - i_2(j\omega m)$

$$= i_a\left(\frac{r_1 + j\omega l_1}{1 + \frac{z_1}{z_2}}\right) - i_a\left(\frac{j\omega m}{1 + \frac{z_2}{z_1}}\right)$$

and $$Z_p = \frac{v}{i_a} = \frac{(r_1 + j\omega l_1)z_2 - j\omega m z_1}{z_1 + z_2} \quad .. \quad (16)$$

Now $z_1 + z_2$ is the series impedance of the whole oscillatory circuit,

$$= R + j\left(\omega L - \frac{1}{\omega C}\right),$$

if $R = r_1 + r_2$ and since $l_1 + 2m + l_2 = L$.

Neglecting the resistances in the numerator in comparison with the reactances, we have

$$Z_p = \frac{j\omega l_1\left(j\omega l_2 - \frac{j}{wC} + j\omega m\right) - j\omega m(j\omega l_1 + j\omega m)}{Z}$$

$$= \frac{\frac{l_1}{C} - \omega^2 l_1 l_2 + \omega^2 m^2}{Z} \quad .. \quad .. \quad (17)$$

We see also that i_1 will $= -i_2$ if $z_1 = -z_2$, *i.e.*, if

$$r_1 + j\omega l_1 + j\omega m = -r_2 - j\omega l_2 + \frac{j}{\omega C} - j\omega m.$$

Again neglecting the resistances, this is true if

$$j\omega l_1 + j\omega l_2 + 2j\omega m - \frac{j}{\omega C} = 0$$

$$\text{or } j\omega L - \frac{j}{\omega C} = 0,$$

which holds at resonance and very nearly round about resonance.

So that what we have assumed is that nearly the same current flows in AB as in AC, or the oscillatory current is large compared with the anode current.

We have defined the ratio of the voltage across AB to that across BC as b. That is, with our approximations,

$$b = \frac{j\omega l_1 + j\omega m}{j\omega l_1 + j\omega l_2 + j\omega m} = \frac{l_1 + m}{l_1 + l_2 + 2m}$$

Introducing this into equation (17),

$$Z_p = \frac{\frac{l_1}{C} - \omega^2 l_1 l_2 + \omega^2 m^2}{Z} \text{ and writing } \omega^2 = \frac{1}{LC}$$

$$= \frac{l_1 L - l_1 l_2 + m^2}{CZL} = \frac{l_1(l_1 + l_2 + 2m) - l_1 l_2 + m^2}{CZL}$$

$$= \frac{l_1^2 + 2ml_1 + m^2}{CZL} = \frac{(l_1 + m)^2}{L^2} \cdot \frac{L}{CZ}$$

$$= b^2\frac{L}{CZ} \text{ as before.}$$

Formula (14) can be identified with formula (16) if for the effective impedance of AB we write z_1, and for the effective impedance of BCA we write z_2.

Formula (14) then becomes

$$Z_p = \frac{z_1 z_2}{Z} =$$

$$\frac{(r_1 + j\omega l_1 + j\omega m)\left(r_2 + j\omega l_2 - \frac{j}{\omega C} + j\omega m\right)}{Z}$$

$$= \frac{(r_1 + j\omega l_1)z_2 + j\omega m z_2}{Z}$$

$$= \frac{(r_1 + j\omega l_1)z_2 - j\omega m z_1}{Z}$$

which is formula (16).

The current in the oscillatory circuit is

$$i_a \times \frac{j\omega Lb}{Z}$$

and the voltage available across the condenser is

$$v = i_a \times \frac{j\omega Lb}{Z} \times \left(-\frac{j}{\omega C}\right)$$

$$= i_a \times b\,\frac{L}{CZ} \qquad \ldots \qquad \ldots \qquad (18)$$

Now

$$i_a = \frac{\mu e_g}{R_a + b^2\frac{L}{CZ}}$$

$$\therefore \quad v = \frac{\mu e_g}{R_a + b^2\frac{L}{CZ}} \times b \times \frac{L}{CZ} = \frac{\mu e_g}{\frac{CZ}{bL}R_a + b} \qquad (19)$$

This is a maximum when

$$\frac{CZ}{bL}R_a + b$$

is a minimum, which differentiating with regard to b, is when

$$-\frac{C^2}{b^2L}R_a + 1 = 0 \quad \text{or} \quad b^2 = \frac{CZ}{L}R_a$$

and when the circuit is tuned

$$b^2 = \frac{CRR_a}{L}$$

and we can write

$$v = \mu e_g \frac{\frac{bL}{CR_a}}{Z + \frac{b^2L}{CR_a}} \qquad \ldots \qquad \ldots \qquad (20)$$

The increase in the decay factor is now

$$\frac{1}{2L}\,\frac{b^2L}{CR_a},$$

and when b has its optimum value this is

$$\frac{1}{2L}\,\frac{L}{CR_a} \times \frac{CRR_a}{L} = \frac{R}{2L}.$$

In other words, the best arrangement is that which makes the damping introduced by the valve the same as that of the oscillatory circuit.

In our example above we should have the optimum value of

$$b^2 = \frac{CRR_a}{L} = \frac{1{,}000 \times 10^{-12} \times 10 \times 25{,}000}{4{,}000 \times 10^{-6}} = \frac{1}{16},$$

so that $b = \frac{1}{4}$, or, roughly, one quarter of the coil should be tapped off to the anode.

The voltage amplification without reaction would now be 2μ. Since the decay factor is now only doubled by the valve, instead of being made twenty times as great, the selectivity without reaction is very considerably increased, and the reaction necessary to obtain the best signals is also very considerably reduced.

To find in the case of back coupling the effect of the mutual inductance between grid and anode coils we see as before that the grid voltage is increased by

$$j\omega M \times (\text{oscillatory current}) = j\omega M \times \frac{j\omega Lb}{Z}\,.\,i_a,$$

and we can write

$$v_g = e_g + \frac{\omega^2 MLb}{Z}\,i_a$$

and

$$i_a = \frac{\mu v_g}{R_a + Z_p} = \frac{\mu\left(e_g + \frac{\omega MLb}{Z}\,i_a\right)}{R_a + Z_p}$$

or

$$i_a = \frac{\mu e_g}{R_a + Z_p - \frac{\mu\omega^2 MLb}{Z}} \qquad \ldots \qquad (21)$$

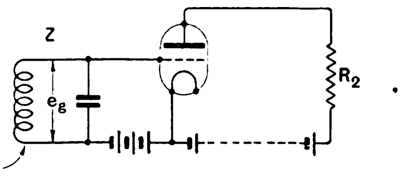


Fig. 10. *Showing the parallel resonance circuit in the grid circuit of the valve.*

and the voltage available across the condenser

$$= i_a \times b\,.\,\frac{L}{CZ}$$

$$= \frac{\mu e_g}{\frac{R_aCZ}{bL} + \frac{b^2L}{CZ} \times \frac{CZ}{bL} - \frac{\mu\omega^2 MLb}{Z} \times \frac{CZ}{bL}}$$

$$= \frac{\mu e_g}{\frac{R_aCZ}{bL} + b - \frac{\mu M}{L}} \qquad \ldots \qquad \ldots \qquad (22)$$

and oscillations start when the denominator is zero, or when

$$M = 1/\mu\left(\frac{R_aRC}{b} + bL\right) \qquad \ldots \qquad (23)$$

3. If the tuned circuit is on the grid side of the valve, so that the condenser of the circuit is connected across the grid and filament, and if suitable negative grid bias is employed and the valve worked along the straight part of its characteristics, then no grid current will flow and the valve will not

damp the oscillatory circuit. Under these circumstances, when there is no reaction, if e is the electro-motive force acting in the oscillatory circuit, and there is a loud resistance R_2 in the anode circuit, we have for the oscillatory current $i=e/Z$ and for the voltage on the grid

$$e_g = \frac{e}{Z} \cdot j\omega L$$

very nearly. The anode current is

$$i_a = \frac{\mu \cdot \frac{e}{Z} \cdot j\omega L}{R_a + R_2}$$

and the voltage available across R_2 is

$$v = \frac{\mu \frac{e}{Z} \cdot j\omega L \cdot R_2}{R_a + R_2} = e \cdot \frac{\mu \cdot j\omega L}{1 + \frac{R_a}{R_2}} \cdot \frac{1}{Z} \qquad (24)$$

which when R_2 is made equal to R_a and the

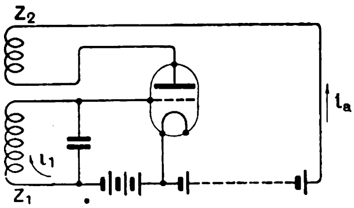


Fig. 11. *Introducing reaction into the grid oscillatory circuit.*

frequency is that of resonance, becomes

$$e \cdot \frac{\mu \cdot j\omega L}{2} \cdot \frac{1}{R} = je \cdot \frac{\mu}{2} \cdot \frac{1}{R}\sqrt{\frac{L}{C}}$$

With our previous example if $\mu = 10$

$$v = e \times \frac{10}{2} \cdot \frac{1}{10}\sqrt{\frac{4{,}000 \times 10^{-6}}{1{,}000 \times 10^{-12}}} = 1{,}000\, e.$$

The voltage amplication is a thousandfold. The decay factor is unaltered as is seen from the fact that in the complete expression for v, $1/Z$ is multiplied by a constant.

If the resistance R_2 is replaced by a tuned anode circuit the resonance curve as ω is varied is no longer a simple one This case it is hoped to deal with in a later article.

If reaction is introduced, say by replacing the resistance R_2 by a coil of inductance L_2 and resistance R_2 (impedance Z_2) coupled with the first coil by a mutual inductance M, then distinguishing the grid oscillatory circuit by the subscript 1, we have for the anode current

$$i_a = \frac{\mu e_g - j\omega M i_1}{R_a + Z_2}$$

since there will be an E.M.F. $j\omega M i_1$ acting in the anode circuit as well as the equivalent voltage μe_g; and for e_g we have the voltage across the condenser, giving

$$e_g = -\frac{j}{\omega C_1} i_1$$

Hence we have

$$i_a (R_a + Z_2) + j\left(\frac{\mu}{\omega C_1} + \omega M\right) i_1 = 0 \qquad (25)$$

and also

$$i_1 Z_1 + j\omega M i_a = e \quad .. \qquad (26)$$

from a consideration of the electromotive forces acting in the oscillatory circuit.

Eliminating i_a from these two equations we find

$$\frac{e - i_1 Z_1}{j\omega M} (R_a Z_2) + j\left(\frac{\mu}{\omega C_1} + \omega M\right) i_1 = 0$$

$$j\frac{Z_1}{\omega M} (R_a + Z_2)\, i_1 + j\left(\frac{\mu}{\omega C_1} + \omega M\right) i_1$$

whence

$$= \frac{je}{\omega M} (R_a + Z_2)$$

$$i_1 = \frac{e}{Z_1 + \omega M \left(\frac{\frac{\mu}{\omega C_1} + \omega M}{R_a + Z_2}\right)} \qquad (27)$$

We note that if $M=0$, $i_1=e/Z_1$ as it should.

The effect of M will depend upon its sign, that is upon the way the coil Z_2 is arranged with regard to the coil of Z_1. If M is positive the effective resistance of the circuit and its decay factor are increased. If M is negative there may be either an increase or a decrease according to the value of M, but there will be a decrease unless M is unusually large. Writing—M for M, we have for the effective impedance

$$Z_1 - \frac{M \cdot \frac{\mu}{C_1}}{R_a + Z_2} + \frac{\omega^2 M^2}{R_a + Z_2}$$

If $\mu M/C_1$ is greater than $\omega^2 M^2$, that is, M less than $\mu/C_1\omega^2 = \mu L_1$ at resonance, there will be a decrease of impedance and effective resistance, but if M is greater than μL_1, an unlikely condition, there will be an increase.

Generally the impedance of the coil L_2 will be much less than R_a, and instead of $R_a + Z_2$ we may write simply R_a.

We then have that the effective resistance of the circuit is

$$R_1 - \frac{\mu M}{R_a C_1} + \frac{M^2}{L_1 C_1 R_a}$$

of which the last term is usually negligible, since M/L_1 will usually be very small compared with μ. Oscillations start when the effective resistance is zero, or when $M = R_1 C_1 R_a/\mu$, in our example

$$\frac{10 \times 1{,}000 \times 10^{-12} \times 25{,}000}{10} = 25\mu\text{H}.$$

The decay factor also will be decreased, by

$$\frac{\mu M}{2 R_a L_1 C_1}.$$

If now, instead of using grid bias, the valve is made to rectify by means of a grid leak there will be grid current flowing through an equivalent valve resistance R_g and there will be damping of the oscillatory circuit by the valve in the same way as when the oscillatory circuit was connected to the anode, and the coupling must be increased to compensate for this. And in the same way that it was found in the anode case to be better to tap off only a portion of the coil to the anode, it may be found that it is better to tap off only a portion of the coil to the grid.

In any of the cases considered, if the voltage or current in the circuits is plotted against ω a simple resonance curve results which when treated by the circle construction described in section 1 will give a straight line, from which the effective decay factor of the circuit arrangement is found.

When two tuned circuits are involved the circle is replaced by a parabola. It is hoped to deal with these cases in a further contribution. It will also be shown that in the wireless circuits in general use, whatever the nature of the coupling, it can be replaced by an equivalent mutual inductance. Thus the coupling effect of the valve capacities, which has been ignored in the preceding notes, can be taken account of by a suitable modification of the values of the mutual inductance.

Matters of Wireless Interest at the Physical Society's Exhibition.

As has been the case in recent years, wireless was again represented at the Seventeenth Annual Exhibition of Apparatus held by the Physical Society and Optical Society at the Imperial College, South Kensington, on 4th, 5th and 6th January, 1927.

Following the practice inaugurated last year, in addition to the usual commercial exhibits, a section was devoted to Research and Experiment, *e.g.*, from Government and other research establishments, this section being further embellished by groups of Lecture Experiments and Famous Historical Experiments.

At the stall of the **Cambridge Instrument Co., Ltd.,** the chief wireless exhibit was a multi-range thermionic voltmeter, a development of the now well-known Moullin, pattern A, instrument. This is designed for the measurement of alternating voltages at high or low frequencies over a wider range than was possible with earlier models. Three ranges are now provided in one instrument, *i.e.*, 0-4, 0-40 and 0-120 volts respectively. Another interesting exhibit was their latest pattern of Three Element Oscillograph, which allows simultaneous records to be obtained from three vibrators. These may be any combination of electrostatic or electromagnetic (Duddell) types. The apparatus was demonstrated in operation along with other apparatus, including an Eccles' valve maintained fork, reed hummer, etc.

Messrs. Creed & Co., Ltd., demonstrated the Creed Start-Stop and Murray Multiplex systems. The former is a typewriter keyboard operated transmitter, received signals being printed directly letter by letter in Roman characters. The Murray Multiplex is on the well-known five-unit channel system.

Among the instruments of **Messrs. Crompton & Co., Ltd. (Chelmsford),** the all test Moving Coil Test Set, and the unique Cell Tester were of interest in wireless work.

The Damard Lacquer Co., Ltd., of Birmingham, showed a number of bakelite and other insulating materials.

Darimont Electric Batteries, Ltd., exhibited the latest forms of this primary cell, which is now constructed so that the depolariser is supplied in a dry state, to be dissolved as required for use.

The Dubilier Condenser Co., Ltd., had their usual extensive display of condensers of all sizes and for all forms of wireless work. Practical interest attached to a series of standard condensers of various forms

and high accuracy, and to condensers for transmitting circuits, *i.e.*, for anode feed, high power circuits, smoothers, etc. A large range of receiver condensers were also on view, including the plate by plate model giving smooth variation over a large range. Amongst other sundries a useful mica insulator was shown, and a Neon lamp wavemeter.

Elliott Bros., London, Ltd., showed different patterns of measuring instruments, one of particular interest being a differential cell testing voltmeter of use in localising battery defects due to a particular plate of a cell.

Messrs. Everett Edgcumbe featured several instruments for radio frequencies, both of the thermo-expansion and thermo-couple type. These are also designed for use with iron-cored radio-frequency transformers.

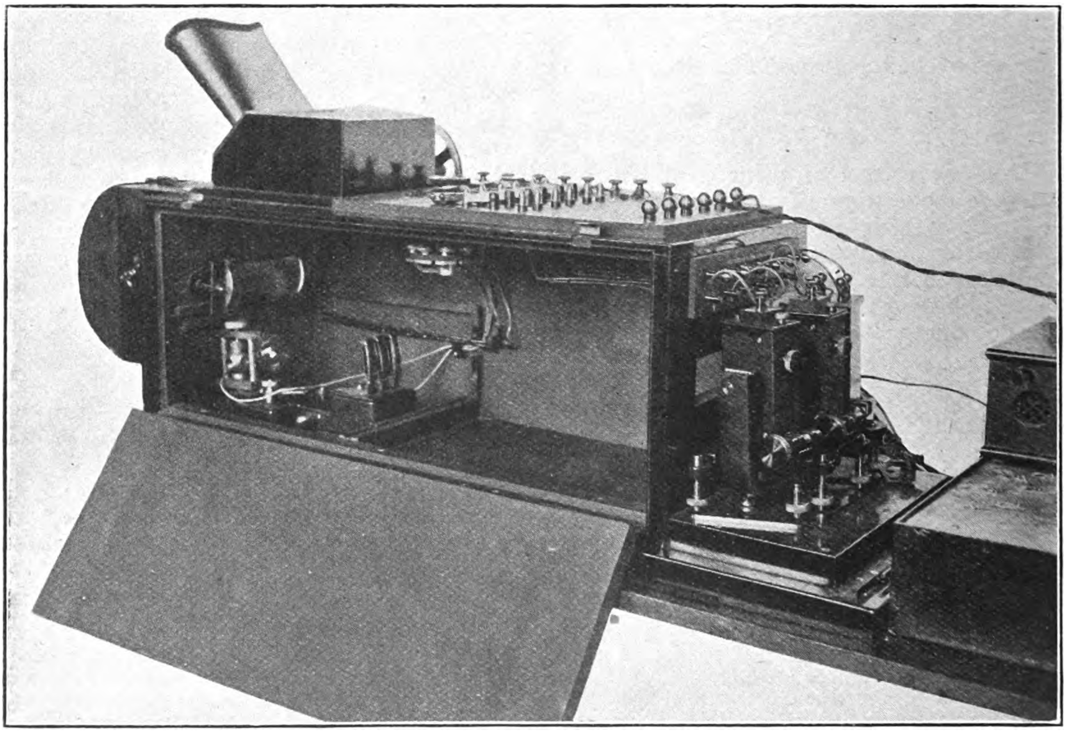
Messrs. Gambrell Bros., in addition to many useful pieces of test apparatus, displayed a series of receivers drawing all voltages, L.T. and H.T., from mains, A.C. or D.C.

Messrs. Adam Hilger and **Messrs. Kelvin Bottomley & Baird** both had quartz crystals on view.

The Igranic Electric Co., Ltd., had a large display of purely wireless interest, including eliminators, a Neutrosonic seven-valve portable receiver, as well as the already well-known supersonic outfit. Amongst other items shown were twin-gang and triple-gang condensers.

The India Rubber and Gutta Percha Works, while showing chiefly telegraph and measuring apparatus; displayed several wireless accessories, including L.F. transformers, loud-speakers, etc.

The Marconiphone Co., Ltd., had on view their well-known "Straight Eight," together with other smaller models, while the **M.O. Valve Co.** had an extensive show of valves of all sizes including components of water-cooled anode valves, and a number of water-cooled anode valves assembled. An interesting exhibit was a low-frequency oscillator, operating at 1 cycle per second. Instruments showed oscillatory current, oscillatory voltage and anode current, enabling the cyclic variations to be readily followed. Various new valves were also on display, including the D.E.P. 215 and K.L. having a separately heated cathode.



Three-element oscillograph. Cambridge Instrument Co., Ltd.

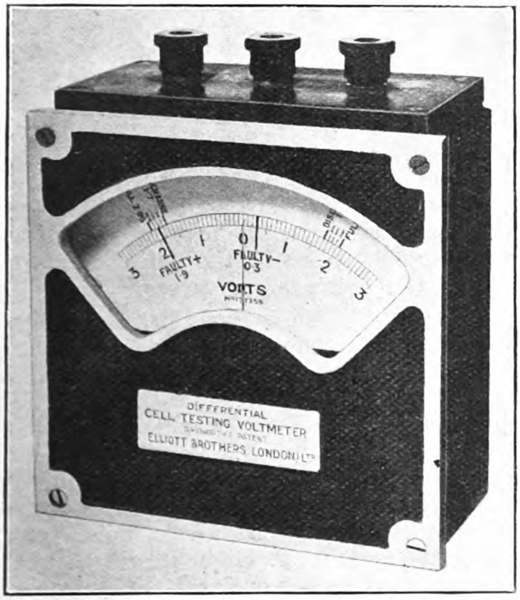
The Mullard Radio Valve Co. and Mullard Wireless Service Co., Ltd., had an extensive display of the well-known P.M. Filament series in 2, 4 and 6-volt groups, parts of valves in various stages of construction, etc. There was also a number of transmitting and (power) rectifying valves, notably the P.M. water-cooled valve. An oscillator at 2.5 metres was also shown in operation.

Measuring instruments of various types were exhibited by **Messrs. Nalder Bros. & Thompson,** and by **The Record Electrical Co., Ltd.,** the latter featuring "Cirscale" instruments, giving a wide (nearly completely circular) scale reading.

Messrs. W. G. Pye & Co., of Cambridge, had a variety of small current galvanometers, while **The Stonebridge Electrical Co.** had also a number of small portable precision instruments of various ranges.

The display of the **Radio Communication Co., Ltd.,** was naturally entirely wireless. Their automatic call device, responding to a series of 4-second dashes, was demonstrated in operation, while another exhibit was a C.W. transmitter of 500-3,000 metres with a sea range of 1,000-1,500 miles, and with provision for I.C.W.

At the stall of **Messrs. H. Tinsley & Co.** many pieces of measuring apparatus were on view, the most recent being, perhaps, the Willans Transformer Tester (see *E.W. & W.E.*, July, 1926), and a wavemeter of N.P.L. design from 500-6,000 metres.



Differential cell-testing voltmeter. Elliott Bros., Ltd.

Messrs. H. W. Sullivan & Co., Ltd., had a large display of laboratory apparatus including A.C. bridges and accessories, a standard multivibrator wavemeter (due to D. W. Dye of N.P.L.), precision heterodyne wavemeters, and wavemeters for very short wavelengths. There was also a display of various apparatus for the determination of effective resistance, inductance and capacity at radio frequencies.

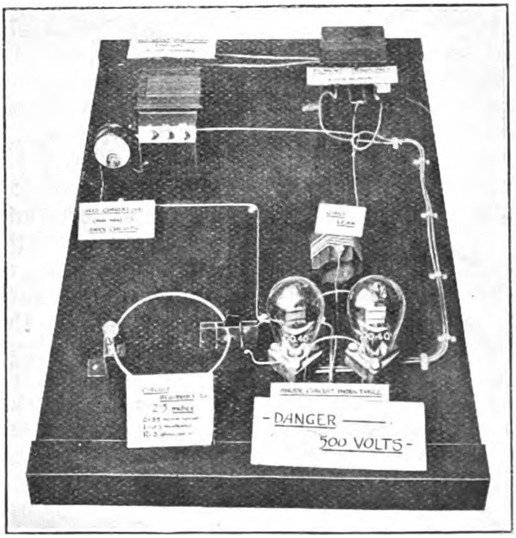
The Weston Electrical Instrument Co., Ltd., showed a large selection of the A.C. and D.C. instruments for which they are well known, an item of special wireless interest being a radio panel voltmeter of only 2 inches diameter for use on receiving sets.

The display of the **Zenith Electric Co.** was chiefly of resistances, including wire wound resistance units of high ohmic value, inductionless and of low capacity.

RESEARCH AND EXPERIMENTAL SECTION.

In Group A (some typical results of recent physical research) the **Admiralty Research Laboratory** showed a signal strength meter for use on waves over 6,000 metres. In the N.P.L. exhibit the only item of wireless interest was apparatus for obtaining standard telephonic frequencies from the seconds given by a clock pendulum. The pendulum maintains a 50-cycle fork, acting in conjunction with a multivibrator.

The Research Laboratories of the G.E.C. showed a model demonstrating the magnetron principle of the effect on space current of an external magnetic field, and skiagrams of water-cooled anode valves. The **Metropolitan Vickers Co.** had a display of short path valves, in the form of exhibits illustrative of the short path principle. The



A short-wave oscillator. Mullard Radio Valve Co.

B.T.-H. Co.'s Engineering Laboratories had an oscillating valve model in the form of a mechanical arrangement illustrating the principles involved in a triode oscillator. **Mr. J. N. Baird** had on view a model of the original television apparatus, as already exhibited at the Wireless Exhibition.

In Group B (Lecture Experiments in Physics) **Mr. G. G. Blake** had a triode valve model designed to illustrate the action of the three-electrode valve, demonstrating the effect of operating conditions and the reception of oscillations. Prof. G. B. Bryan also showed a valve characteristic model demonstrating the relationship between grid voltage and anode current.

In Group C (Famous Historical Experiments in Physics) were four exhibits lent by Prof. E. O. Appleton from the King's College (London) collection: 1. Coil used by Joseph Henry in his work on self-induction; 2. Resistance Box and Bridge used by Mr. Charles Wheatstone; 3. An A.B.C. Telegraph designed by Wheatstone in 1840; and 4. A mechanical model designed by Clerk Maxwell illustrating the induction of currents.

The Acoustic Problems of Microphones and Loud-Speakers.

Informal Discussion at I.E.E. Wireless Section.

THE monthly meeting of the Wireless Section, I.E.E., held on 5th January, was devoted to an informal discussion on "The Acoustic Problems of Microphones and Loud-Speakers."

The discussion was opened by **Mr. G. H. Nash, C.B.E.,** who said that instead of examining the subject from the standpoint of close detail of design—these subjects already being dealt with in numerous papers—he would rather lead the discussion on the lines of considering whether broadcasting was proceeding on the right lines and whether our ideas of what was needed were clear. He compared broadcast with personal attendance, say, at a concert or address—where eyes and other faculties were active. The transmitter and receiver should have a straight line of performance, and microphone and loud-speaker to be ideal should reproduce the complex sensations of the ear. The microphone offered fewer problems than the receiver. The condenser type was the most perfect in existence and had been adopted as an international standard.

He proposed to offer four heads of discussion: 1. To what extent were binaural transmission and reception advantageous? 2. What was the value of the extremes of the musical scale, *i.e.*, 30-60 cycles and 5,000 to 10,000 cycles? 3. Was it expedient to accept weakness in one part of the system and balance it by strengthening some other part? 4. How far could we expect efficiency and wide frequency response in the loud-speaker?

Dealing with the first point, he asked, was it necessary to have those transmitters and receivers so placed as to give the correct impression of the relative positions, movements of speakers, etc.? In the second point he showed that 30-60 cycles band was entirely absent in a wide range of music. In many loud-speakers the lower frequencies were not reproduced as such but were heard on harmonics. The upper end of 5 to 10kC was mostly present as overtones of other frequencies. If these extreme upper frequencies could be omitted the width of sideband would be smaller. Additionally, in estimating the need for their presence, it was very difficult to measure the loud-speaker output.

On the third head he showed a slide of the audio-frequency amplification at WJZ showing a magnified upper scale at the transmitter to compensate for loud-speaker defects. This necessitated increased load on the transmitter and at the receiver called for much greater anode voltages. On the fourth head he considered loud-speaker performance, pointing out that small diaphragms could not respond to low frequencies. Large volume needed larger power valves and increased high tension. The loud-speaker equipment of the future would probably be in the form of mains supply and much larger valves.

Continuing the discussion, **Mr. B. S. Cohen** expressed the opinion that binaural working might be of advantage in transmitting such matter as drama, but that experiment had shown it to be of little advantage for other purposes of reception. By international agreement, three standards of frequency range had been selected: 1. Ideal transmission of all speech, music, noise, etc., 30-10,000 cycles; 2. High quality speech and music, 100-5,000 cycles; 3. Commercial line telephony, 200-3,000 cycles. From tests of loud-speakers it was found that while many responded strongly at their resonant frequencies their outputs at 5kC were small. The difficulties of transmitting up to 10kC had been pointed out and he questioned the necessity of such band width. He then quoted efficiency figures for various types of apparatus, more especially microphones, and discussed possible lines of improvement as regards cavities, stretch of moving parts, etc.

Capt. P. P. Eckersley said that binaural transmission had not been given to the public because it necessitated two receivers. He agreed that it was legitimate to cut off extremes of sidebands, but considered that all frequencies should be transmitted in

order to encourage the development of apparatus in response to them. He did not approve of sending up the transmitter amplification for the higher frequencies and the B.B.C. did not do it. The problem of the best type of microphone for broadcast purposes was considerable. It must have a flat response, negligible background of noise, and maintenance must be simple. He discussed some of the types that had been used and believed that the ideal of these requirements could be obtained.

The Chairman here suggested that the experiment might be tried of using Daventry and London simultaneously for binaural work. Mr. Eckersley replied that it had not been done so far although it was possible and had been considered.

Mr. C. F. Phillips agreed that the transmitter should endeavour to transmit both ends of the musical spectrum. The arguments against this were purely financial and should not govern the case. As regards increased power at the receiver for the wider scale, with the definite tendency towards operation from supply mains, this became unimportant. He had found that when they furnished proper reproduction the public did appreciate it.

Mr. R. P. G. Denman endorsed this view. As regards the lower frequencies, it was certainly necessary to go below 100. The extreme frequencies did produce a gain in results. In comparing a gramophone, with a mechanical cut off at 100, against an electrical system having a falling characteristic but not a cut off, the latter was distinctly better. The loud-speaker used was of the free-edge-cone pattern, coil driven. The interest and appreciation of the public were great, and many people had travelled considerable distances to witness a demonstration of this instrument.

Mr. A. C. Brown urged that consideration to articulation must be given in reproduction. Graham Bell, in his original work on the telephone, had aimed chiefly at this, and articulation must be considered as well as frequency.

Mr. Sandeman discussed the energy spectrum of the matter to be broadcast and that of noise. The lower frequencies carried more energy, so that if they were just sufficient to overcome noise the higher frequencies would not have sufficient energy. Hence arose the need for increased amplification of the higher frequencies. He then discussed the factors governing loud-speaker performance, regarding the loud-speaker in much the same way as an aerial and having a radiation resistance at its horn or diaphragm (in the case of cone types) and showed the difficulties of efficiency at the lower frequencies.

Mr. A. G. D. West agreed that efficiency and quality were antagonistic. The ordinary telephone receiver had a bad frequency characteristic and recently developed forms had better characteristics but were less efficient and necessitated more valves. It was still impossible to get a loud-speaker good below 100 cycles, and even the model mentioned by Mr. Denman distorted below this value. The increased transmitter amplification at the higher frequencies was chiefly to compensate for the inefficiency of the horn loud-speaker.

Mr. P. K. Turner said that binaural reception was a matter of phase, and that in broadcasting there was no guarantee of phase and therefore the arrangement was not applicable. As regards the extremes of frequency, he had tested two sets, one doing 50 per cent. at 30 and at 7,000 cycles, and the other working to 16 and 16,000 cycles. The better scale of the latter instrument gave a perceptible difference.

Mr. Hart discussed binaural reception and different points of acoustics, and the difficulty of estimating or measuring the amount of the sensation of hearing.

Mr. Nash briefly commented on several of the points raised in the discussion, more especially on the width of the band.

In concluding the meeting, the Chairman (**Prof. C. L. Fortescue**) said that the discussion had shown several questions to be settled. In America, thousand of observers had been used, and it was possible that we should have to refer to thousands of musicians in this country. Was a musical ear one that could distinguish everything, or did it produce a blend? The ultimate decision might be physiological or psychological rather than electrical.

Book Reviews.

RADIO FREQUENCY MEASUREMENTS: A HANDBOOK FOR THE LABORATORY AND A TEXT-BOOK FOR ADVANCED STUDENTS. By E. B. Moullin, M.A. Pp. 278 + xi., with 134 Figs. Griffin. 25/-

The subject of radio frequency measurements is one of wide interest which grows very rapidly. It is, on this account, a matter of considerable difficulty to choose and arrange the subject matter of a book on the subject which will not quickly lose its value by reason of new developments in the science of the practice and in the art of the methods of measurement at radio frequencies.

The present book is entitled *A Handbook for the Laboratory and a Text-Book for Advanced Students*. Within the compass of its two hundred and seventy pages, the book appears to fulfil its function fairly well; in particular, the book is very free from obsolete matter although, naturally, it does not contain a large amount of novel matter.

The book is divided into nine chapters headed in order, (1) the valve oscillator, (2) measurement of potential difference and current, (3) measurement of frequency, (4) measurement of resistance, (5) measurement of capacity, (6) measurement of inductance, (7) measurement of antenna characteristics, (8) measurement of intensity of radiated fields and (9) miscellaneous measurements and notes.

At a first reading through, one misses a chapter on the general mathematics of circuits, but a closer reading shows that in each chapter the mathematics requisite to the section is quite sufficient as given in the section. Less repetition than might be expected occurs. A certain amount is inevitable since at radio frequencies we cannot separate the properties of circuit into water-tight compartments and say "this" is inductance and "that" is capacity. Resistance also must be very carefully defined as is well perceived and set out by the author.

Chapter I., dealing with the valve generator, is all too short. Too much emphasis cannot be laid upon the importance of the valve generator in radio-frequency measurements. It will be found in the great majority of cases that troubles and difficulties of measurements in which a valve generator is used, arise from irregularity and drifting of frequency and amplitude or insufficiency of its power. In this connection mention might have been made of the use of independently driven oscillators in which a small master valve produces the oscillations and energises the grid-filament circuit of a larger power valve.

The second chapter, dealing with potential difference and current, naturally gives prominence to the author's thermionic voltmeter, but the use of such an instrument to calibrate a thermo-junction heater of moderate resistance is open to question as it is probable that a considerable part of the differences in the ratio of readings of the two instruments as a function of frequency resides in the thermionic voltmeter rather than in the thermo-heater. The real advantage of the thermionic voltmeter resides in its extreme sensitivity rather than in its accuracy. In connection with the use of electrostatic voltmeters the author omits to mention the most serious drawback to the instrument, viz., the *change* in its capacity with reading. This change immediately causes a resonant circuit to become detuned when an attempt is made to tune the circuit with the voltmeter in parallel and renders it impossible to set the circuit to exact resonance with a source. The use of a thermionic voltmeter to measure small currents by observation of the P.D. across a condenser in series in the circuit concerned is open to serious objections. In the case quoted the reactance introduced by the condenser is 300 ohms. The compensation of this reactance by adjustments to the main condenser or inductance in the circuit is a very objectionable necessity of the method. The same current of 3mA can very readily be measured on a vacuum thermo-heater of 30 ohms resistance.

The suggestion at the end of the chapter to measure large currents by observing the secondary induced voltage in a mutual inductance, using a thermionic voltmeter, has the drawback that the calibration depends to the first order upon frequency. Large errors occur also due to the self-capacity of the secondary and to the capacity of the voltmeter. Harmonics would also produce enhanced voltages in the secondary.

The third chapter, on frequency measurement, is good from the point of view of fundamental or standard arrangements by which a basis of measurement may be established; the treatment is very full but more attention might have been given to the common resonance wavemeter and to the heterodyne wavemeter since these are indispensable in any laboratory and have now reached a considerably accurate stage of evolution. The cathode ray tube method developed by the reviewer has been omitted from the chapter, although it possesses advantages over the other cathode ray tube systems described, and was prior to them.

In the discussion on stationary waves on wires, mention should have been made of the very excellent investigation of the velocity of waves along wires carried out by G. Laville (*Ann. d. Physique*, 1924).

The section on buzzer-excited oscillations is very complete. The treatment of the reinforcement of harmonics of the buzzer frequency is interesting but, in general, the frequency of the buzzer itself is so irregular that the effect of reinforcement of certain frequencies is difficult to obtain, although this property has been used in a similar manner to a multivibrator for purposes of frequency standardisation.

In the reviewer's experience a self-modulated valve oscillator is far more satisfactory than any buzzer wavemeter as a source of modulated radio frequency.

The chapter on the measurement of resistance is one of the best in the book in view of the difficulty of doing justice to the subject. The author shows that he has had considerable experience of resistance

measurements on circuits of moderate or poor decrement (greater than 0.04). The real difficulties of resistance measurement commence when decrements less than 0.01 occur. Such decrements are by no means uncommon in present-day circuits, especially at frequencies above 1,000 kilocycles per sec. The cases for the resistance variation and the reactance variation methods are fairly compared. The reviewer has found the method of frequency variation very satisfactory in many cases, since a frequency difference can be easily set to an accurately known value by the aid of a tuning fork and a small heterodyne oscillator.

On circuits in which the total capacity is smaller than $500\mu\mu F$ and the decrement of the order 0.01, it is practically impossible to use the reactance variation method since changes of only $1\mu\mu F$ are required.

When a resonance curve has been obtained it is generally desirable to measure the breadth across the curve at a number of values of current and to re-plot the results in the form " width of peak " as ordinate to the expression

$$\frac{\sqrt{I^2_{res.}-I^2}}{I^2_{res.}}$$

as abscissa. A straight line should result, having a slope proportional to the log. dec. of the circuit. A valuable check is thereby obtained upon the accuracy of the measurements.

The chapter on capacity first describes various methods of measurement at low or telephonic frequencies. This is quite legitimate in a book on radio-frequency measurements since the foundations of capacity have to be laid in low or telephonic-frequency measurements using good air condensers to step up to radio frequencies. In this connection it is noted that the Carey Foster and the Schering bridges are not mentioned although these two are probably superior to all the others.

In connection with the radio-frequency tests a method, using mutual inductance, is described for measuring losses in a condenser, but it does not appear that the method has ever given satisfactory results. The fact that the mutual inductance must be equal to the self inductance in the oscillatory circuit requires a self inductance in the secondary circuit which is considerably greater than that in the primary. The self capacity of the secondary and losses associated therewith, will entirely invalidate the measurements when these are required to give the losses in an air condenser of good quality.

The presence of two coils each in the magnetic field of the other, such as must occur in any mutual inductance, will necessarily involve what may be termed a mutual resistance common to the two windings. It is very difficult to measure this resistance and it may have a value many times that under measurement, in the case of a good air condenser.

The measurement of dielectric losses has been dismissed in a short paragraph; the subject is, however, one of considerable importance and merits a much fuller discussion.

The chapter on inductance is good, in particular the section dealing with the measurement of coil resistance and the theoretical excerpts from Butterworth's classical papers are noteworthy. It is noted that in the discussion of the separation of the self-capacity and effective geometrical inductance it is stated that the curve connecting λ^2 with " added capacity " is an accurate straight line. This, however, is only true if the wire of the coil is of such small cross section that the effect of eddy currents on the true inductance is negligible It will be found with solid wire coils that the line has a curvature in a direction showing smaller inductance at smaller values of λ^2. In such a case the self-capacity cannot be defined from the experimental results. In those cases in which straight lines are obtained very accurate results may be obtained by the use of the formulæ of Hulbert and Breit, making use of the principle of least squares. The immersion method of measuring coil capacity has obvious limitations since it is often undesirable or impossible to immerse coils.

The chapter on antennæ is exceptionally clear and well written. The author has not shirked the difficulties of accurate conception of the true inductance, capacity and resistance of an antenna. The difficulty of visualising the birth of the waves has also been admitted.

With regard to actual analysis of the constants of antennæ the " tuning " of the antenna to certain wavelengths is, of course, frequently referred to. The precise meaning of this has not been defined and it would seem desirable that a clear statement should be made as to what is brought to a maximum under the influence of a constant impressed electromotive force. It is not clear that the second method (7) for determining the effective inductance and capacity of an aerial is superior to the direct method of plotting the line connecting λ^2 with added inductance; it is virtually equivalent to obtaining two points on a line instead of a number of points.

Chapter VIII. is partly an extension of Chapter VII. The difficult subject of effective height of an antenna is dealt with shortly. The measurement of the electric field intensity occupies the next section of the chapter. In this specialised subject the relative values of the various methods used must be largely a matter of opinion and of the capabilities of the various workers in this subject. One important advantage of the use of coil reception systems over antenna methods for the measurement of field intensity is the possibility of measuring the components of the field in various azimuths and also of measuring the downcoming wave. Another advantage of loop or coil systems is that their constants are much more easily measured and are less variable than those of an antenna. Against the much smaller induced electromotive force in the coil may be offset the lower effective resistance in most cases.

In the section dealing with the production of known small electromotive forces for calibrating purposes in connection with field intensity measurement, the use of current transformers as developed by the reviewer has not been mentioned. This method answers nearly all the difficulties associated with such measurements, except at very high radio frequencies. The current transformer is a form of mutual inductance which is nearly ideal.

The final chapter deals with miscellaneous measurements and notes; these are necessarily somewhat disjointed as they fall outside the general

plan of classification of the book. The chapter includes notes on the following subjects : Measurement of harmonics, amplification of amplifiers, equations of a transformer, rectification with a heterodyne, analysis of resonance built up by impulses (multivibrator for example), and finally the resonance frequency of compound circuits. Obviously these matters can only be dealt with sketchily in the twenty pages forming this chapter.

Taken altogether the book may be said to be very readable and all the matter contained in it is interesting. The choice of matter for such a book is one of considerable difficulty, and in this book it is too much to expect that it will meet with universal approval, since many will desire a more detailed description of the procedure in carrying out measurements and in the choice and set up of apparatus which is required, than will be found in the book.

The book is very free from errors, the only errors noted are of small importance : on p. 5, A should be a, and on p. 165 the expression on line 7, $h=E \sin pt$, should be $h=H \sin pt$. D. DYE.

DAS ELEKTRISCHE FERNSCHEN UND DAS TELEHÖR (Television). By Dénes von Mihály. Pp. 196, with 112 Figs. M. Krayn, Berlin.

This is the second enlarged edition of a book first published in 1923. Since 1923 the subject of Television has been worked at with considerable success, especially in this country by Baird, whose success has centred attention on the subject. Mihály of Budapest has devoted much attention to the subject, and in this book goes into the matter very fully. After stating the problem and pointing out the difficulties, he gives a historical review of the methods which have been suggested and tried, including some of his own. A short section towards the end is devoted to the transmission of pictures and writing, a very different proposition but one which has many points in common with Television.

G.W.O.H.

LES FILTRES ELECTRIQUES : Theory, Construction, Applications. By Pierre David, with a Preface by Général Ferrié. Pp. 130, with 76 Figs. Gauthier-Villars, Paris. 25 fr.

Electric filters are combinations of circuits allowing complex currents to be analysed according to their frequency, those of desired frequencies being allowed to pass, those of undesired frequencies being cut out. A great amount of research has been done on this subject in recent years, especially in America. The present book recapitulates and presents this work in a complete homogeneous form ; in addition to the theory it gives practical rules for the construction of filters to meet given specifications, together with tables and curves. Practical examples are given showing how nearly experimental results agree with the calculations.

The book concludes with a very useful classified bibliography giving 67 references. G.W.O.H.

DER BAU VON WIDERSTANDS-VERSTÄRKERN (Construction of Resistance-coupled Amplifiers). By Manfred von Ardenne. Pp. 142 with 85 Figs. R. C. Schmidt & Co., Berlin. 3.60 marks.

No one has devoted more attention to the possibilities and limitations of resistance-coupled amplifiers than von Ardenne. His work is well known, especially that in conjunction with Dr. Loewe—who has written a foreword to this book—whereby they have developed the multiple valve with the components of three valves and the coupling resistances and condensers all assembled in a single bulb not much larger than an ordinary valve. This second edition of von Ardenne's book deals very fully with the theory and design of resistance-coupled amplifiers, every point is discussed and very fully and clearly illustrated by means of practical examples. We do not agree with every statement made, but we unreservedly recommend the book to all those interested in the subject, who have the necessary knowledge of German.

G.W.O.H.

ALTERNATING CURRENT RECTIFICATION. By L. B. W. Jolley, M.A. Pp. xxii. + 472, with 340 Figs. Messrs. Chapman & Hall. 30s.

The first edition of this book was published in 1924 and that a second edition is called for so soon indicates the widespread interest in this subject. The book is divided into seven parts, of which the first is purely mathematical ; succeeding parts deal with mechanical rectifiers, gaseous rectifiers, electrolytic rectifiers, wireless rectifiers, inverters, applications of rectification to measurements, etc. The impression gained from a perusal of the book is that the author is a mathematician rather than an electrical engineer. When he is dealing with the mathematical analysis of any process of rectification he is on safe ground but his descriptions of the mode of operation are sometimes anything but convincing. As an example we would give the description of the motor-convertor on page 80 with such statements as " the driving unit is an induction motor which is quite separate from the convertor," a mis-statement which is somewhat supported by the very misleading diagrammatic sketch on page 81. Another example occurs on the following page, where a diagram is supposed to represent a two-part commutator; unfortunately the draughtsman appears to have made a mistake in putting brushes where there should have been fixed connections, but even more unfortunately the author has followed the draughtsman in his description of the operation of the commutator and thus leaves the production of unidirectional current by this simplest of all devices a profound mystery. We regret that the author did not confine himself to the mathematics of rectification and leave these more practical matters to a suitable collaborator.

G.W.O.H.

H.T. and L.T. from a 250-volt D.C. Supply.

By A. Robertson.

MANY systems for utilising the electric light mains for anode current supply in wireless receivers have been described recently in the Press.

Few of these have embodied satisfactory smoothing arrangements, and would therefore be incapable of dealing with town main current in which a commutator ripple was present.

The arrangements about to be described have all been tried out and proved successful on a 250-volt D.C. supply, obtained from 25 cycle, 6-phase rotary convertors.

This supply required a considerable amount of smoothing out in order to get rid of the hum from the converting plant in the sub-station.

The smoothing was not deemed satisfactory until it became impossible to tell, by listening on the headphones, whether the set was running from a battery or from the town main supply.

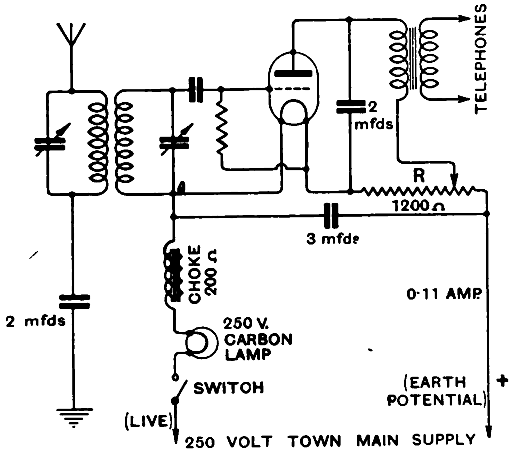


Fig. 1.

All the tests were made on a supply taken from the "negative" side of a 3-wire D.C. system.

Fig. 1 shows a simple one-valve receiver in which both the L.T. and H.T. supplies are taken from the electric light mains.

As this supply is taken from the "negative" side of a 3-wire D.C. system, the + terminal is at earth potential and the — terminal 250 volts below earth. The earth lead should therefore be connected to the receiver through a condenser capable of withstanding

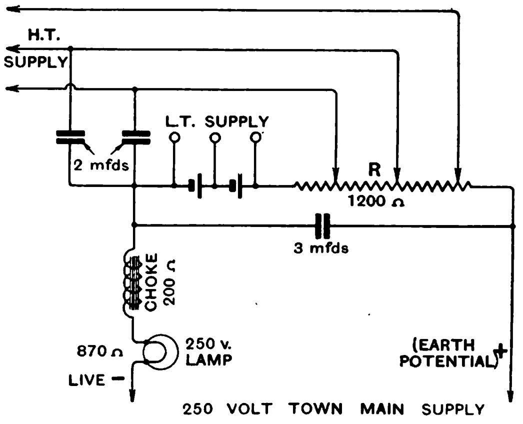


Fig. 2.

the full town main voltage. It was experimentally determined that the best position for the choke coil was at the "live" town main terminal. Results obtained from choke coils connected at "earthed" town main terminal and also in anode circuit, did not justify their inclusion in the circuit. A 3μF condenser was connected between the receiver side of choke coil and + town main terminal, to by-pass any ripple which succeeded in passing through the choke coil. The condensers in anode circuit function as reservoirs and contribute little or nothing towards smoothing of ripple.

A choke coil connected in the wrong place may defeat its object. For example: a choke coil inserted between the + L.T. battery terminal and resistance *R* (Fig. 2) will cause the hum to reappear. This result, though not unexpected, indicates that the resistance *R* should be of a non-inductive type.

This resistance consists of a bank of twelve low voltage carbon lamps having a total resistance of about 1,200 ohms. The resistance of the choke coil is 200 ohms, making the total resistance of circuit connected to town mains about 2,270 ohms, which allows a current of .11 amp to be drawn from supply. This represents 27.5 watts and costs one penny per week of 36 hours, with electricity at one penny per unit. Provision was made for obtaining the requisite H.T. voltages for each valve by taking a tapping from each lamp, in resistance *R*, to a wander plug socket. A voltage range up to 130 volts was thus available in twelve steps of approximately 11 volts each.

Carbon lamps were used in preference to a wire wound resistance in order to prevent the sudden rush of current through valve filament, which would otherwise occur when set is switched on.

The space occupied by the resistance, chokes and condensers is less than that required for a H.T. battery for a similar voltage.

A two-valve (H.F. and Det.) receiver with both valves in parallel, was run entirely from town main supply and proved entirely satisfactory whether receiving local or Continental stations.

Fig. 2 shows an arrangement which the writer has used for some time in connection with a three-valve receiver. The L.T. battery has been retained in this case for reasons of flexibility, as valves having very different filament requirements are used on this set.

The L.T. battery is connected in series with the resistance *R* in the town main supply circuit. It consists of a 6-volt alkaline accumulator divided into two units of 3 volts each, fitted with sockets, so that the filament circuit can be connected to either unit by means of a two-pin plug. This plug is changed over on alternate weeks, an arrangement which permits one unit to be charged up while the set is in operation, while the other unit either remains floating or slightly discharging, according to filament requirements.

Experience proved that the current of .11 amp. taken from town mains, while receiver was in operation, was sufficient to maintain the L.T. battery without any additional charge.

The present installation has been in use for nearly a year, during which period the battery has required no attention, apart from an occasional "topping up" with water. There has been no failure of any kind since it was put into operation.

There is little or no risk of damaging valve filaments through accidental contact with H.T. supply, as the current from this supply is limited to .11 amp which is not sufficient to do any harm.

Telephone transformers provide adequate protection against shock. The writer has employed and obtained excellent results from a type of transformer which, so far as he is aware, is quite new. Its operation can best be explained by the following experiment. A small power valve is connected up as shown in Fig. 3, an ammeter is connected to the + and — filament terminals and also in the anode circuit.

With a filament current of, say, .11 amp and the H.T. wander plug disconnected from battery, both filament ammeters will read alike (*i.e.*, .11 amp each).

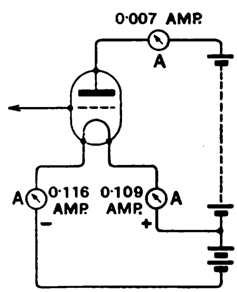


Fig. 3.

When the H.T. wander plug is connected to a suitable supply and a current of, say, .007 amp taken by anode, the two ammeters in filament circuit no longer show a like reading. The + ammeter reading will now have decreased by about .001 amp and the negative ammeter increased by about .006 amp. (With the L.T. battery reversed these readings would become .002 and .005 respectively.) A perceptible diminution in the light from valve filament would be noticed when anode current was switched on.

As a result of the above experiment, the writer obtained a three-winding transformer having a resistance of 25 ohms per winding, and connected up in the filament circuit in

such a manner that the filament current passed up one leg of transformer and returned through the other leg in a direction such as to neutralise the magnetic flux due to the steady filament current (Fig. 4).

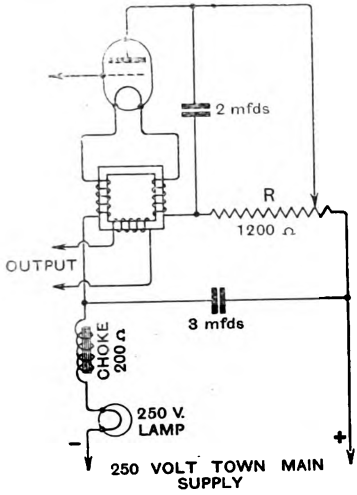


Fig. 4.

A variation in the anode current due to reception of wireless signals caused a reduction of flux in one leg of transformer and an increase in the other leg. A voltage was thus induced in the third winding which could either be used as a telephone transformer or an intervalve transformer or, if desired, the third winding could be connected between grid and filament of its own valve, in which case a very effective L.F. oscillator would be obtained.

The extra resistance which such a transformer introduced into filament circuit proved to be of no disadvantage when used in conjunction with the town main L.T. supply.

The data given are suitable for a three-valve receiver with the following average running conditions :—

About 4 hours per night with 2 valves on local station.

About 1 hour per night with 3 valves on distant station.

And an occasional whole evening's programme with 3 valves on distant station.

It is assumed that loud-speaker reception is desired in each case and that the valves used are as follows :—

One power valve taking .12 amp, together with detector and H.F. valves taking .06 amp each.

If all three valves are of the .06 amp type, the battery will be overcharged as the input to batteries would always be in excess of the output whether all three valves were always in operation or not.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto - Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

AMATORA LONG-DISTANCA LABORADO.—H. N. Ryan.

La perioda kontribuaĵo pri ĉi tiu temo pritraktas lastatempajn rezultojn ĉe malfortaj sendiloj.

PROPRECOJ DE ĈIRKVITOJ.

KVARCAJ KRISTALOJ KAJ ILIA PRAKTIKA APLIKADO AL SENFADENAJ CIRKVITOJ.—Prelego legita antaŭ la Radio-Societo de Granda Britujo, je 24a Novembro, 1926a, de S-ro. A. Hinderlich, M.A.

Post mallonga historia enkonduko, la proprecoj de kvarcaj kristaloj estas diskutitaj kaj detaloj donitaj pri la manipulado, muntado, k.t.p. La uzado de la kristalo kiel resonatoro kaj oscilatoro estas poste priskribita, kun ilustrajoj de diversaj konektaj aranĝoj por la lasta celo.

Sekvas rimarkigoj pri funkciado kaj provado de la kristaloj, kaj sekcioj pri elementaj kaj altgradaj aplikoj, enhavante la uzadon de kvarcaj oscilatoroj kiel frekvencaj normoj, sendila kontrolado, k.t.p.

La diskutado, kiu sekvis la legadon de la prelego, estas ankaŭ presita.

LA DESEGNADO DE ALTERNKURENTAJ ONDFORMOJ.—H. A. Thomas.

Enkonduka Sekcio pritraktas la neceson por

kono pri enmetaj-elmetaj ondformoj de amplifikatora aŭ sendila sistemo. Por frekvencoj ĝis ĉirkaŭ 300 cikloj estas priskribita kaj ilustrita la uzado de Einthoven'a Galvanometro, kune kun rapidega fotografilo (Tipo de *Bureau of Standards* Usona Oficejo de Normoj), kaj tipaj fotografaĵoj montritaj. Por plialtaj frekvencoj, la uzado de Katod-Radia Oscilografo (Tipo de *Western Electric*) estas priskribita kaj ilustrita. La uzo de la ekscitiga fonto por provizi tempan skalon al la oscilografo estas unue montrita. La metodo por interpreti la rezultantan Lissajous'an figuron estas diskutita. Linia tipo de tempo-bazo, ŝuldata al Appleton, Watt, kaj Herd, estas poste priskribita kaj la speco de figuraĵo obtenita estas montrita. La tuta ekipaĵo uzanta ĉi tiun bazon estas tiam priskribita kaj ilustrita fotografe.

SENDADO.

KELKAJ NOTOJ PRI DESEGNAJ DETALOJ DE ALTPOTENCA RADIO-TELEGRAFA SENDILO UZANTA TERMIONAJN VALVOJN.—Resumo de Prelego legita de D-ro. R. V. Hansford kaj S-ro. H. Faulkner, B.Sc., antaŭ la Senfadena Sekcio de la Institucio de Elektraj Inĝenieroj, Londono, je la, Decembro, 1926a.

La prelego pritraktas diversajn difinitajn punktojn pri desegnado, precipe de la Rugby'a Stacio. Oni dividis la temon je 6 sekcioj :—

I. Plej taŭga antena cirkvito laŭ vidpunkto de elimino de harmonikoj ;
II. La desegno de la elektraj proporcioj de la antena cirkvito ;
III. La induktancaj bobenoj por la antena cirkvito ;
IV. Kelkaj notoj pri desegnado de valvaj cirkvitoj, kaj la kondiĉoj de valva funkciado ;
V. Klavado kaj formo de signaloj ;
VI. Lastatempaj rezultoj ĉe Rugby.

Presita ankaŭ estas raporto pri la diskutado, kiu sekvis la legadon de la prelego.

TELEFON-SENDILA MODULADO MEZURITA ĈE LA RICEVA STACIO.—L. B. Turner.

La metodo priskribita estas simpla metodo, facile aplikebla al ekzistantaj riceviloj, kaj ne postulas konon pri la valvaj konstantoj. En la okazo pritraktita, la metodo estas aplikita al krada rektifikatoro sekvanta unu ŝtupon de altfrekvenca amplifado. La metodo konsistas je la momenta mezuro, pere de Moullin-tipa termiona voltmetro, de la voltkvanto transe de la malaltfrekvenca ŝokbobeno dum iu elektita brodkasta programero. La modulo tiam ekzistanta estas esprimita per terminoj de konataj rezistancoj enmetitaj en la anodan cirkviton. La aparato kaj procedo estas priskribitaj, kaj la derivo de la formulo sekvita, kaj ekzemploj de mezurado estas donitaj, montrantaj modulajn proporciojn variantajn de 15 ĝis 61 procento.

En redaktora artikolo oni faras kritikon pri la formulo derivita kaj sugestas plisimplan formulon, kun tabela komparo de la modula proporcio, kalkulita per la du formuloj.

RICEVADO.

KVIN-VALVA RICEVILO KUN 2 ALTFREKVENCAJ ŜTUPOJ POR 900-3,000 METROJ. —W. James.

La aparato priskribita uzas agorditan enmeton, du ŝtupojn de altfrekvenca amplifado, detektoron, kaj 2 malaltfrekvencajn ŝtupojn. La altfrekvencaj ŝtupoj estas kuplitaj transformatore, kun la sekundarioj agorditaj. Oni diskutas la elekton de la valvoj, altfrekvencan kuplon, kaj atingon de stabileco. La konstruo de la altfrekvenca transformatoro estas priskribita, kaj la altfrekvencaj kaj malaltfrekvencaj amplifikatoraj sekcioj diskutitaj detale. Dimensia aranĝo kaj la fina aspekto estas ilustritaj, kaj fina sekcio priskribas la funkciigon de l'aparato.

DIVERSAĴOJ.

RESUMOJ KAJ ALUDOJ.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato) kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

VENONTAJ LEKCIOJ.

Oni anoncas ke serio de ses lekcioj pri " Mallongaj Elektraj Ondoj traktitaj Eksperimente," de S-ro. J. H. Morrell, M.A., estos donita ĉe la Orienta Londona Kolegio, Mile End Road, Londono, E., je 6a horo p.t.m., je lundo, 7a Februaro, kaj sekvantaj lundoj.

MATEMATIKO POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

La serio estas daŭrigita el antaŭaj numeroj. La nuna parto traktas pri solvo de ekvacioj kaj kompleksaj numeroj, montrante la signifon de simbolo " i," la adicion, la multiplikon, k.t.p. de kompleksaj numeroj, kaj la apliko al la ĝenerala ekvacio de la *n*a grado.

Abstracts and References.

Compiled by the Radio Research Board and reproduced by arrangement with the Department of Scientific and Industrial Research.

PROPAGATION OF WAVES.

ON WIRELESS INTERFERENCE PHENOMENA BETWEEN GROUND WAVES AND WAVES DEVIATED BY THE UPPER ATMOSPHERE.—E. V. Appleton and M. Barnett. (*Proc. Royal Society*, 113, A764, pp. 450-458.)

A paper dealing with the problem of the cause of the natural succession of interference effects, which constitutes fading at moderate distances and takes place continuously throughout the night-time, summarised as follows :—

1. Photographic records of interference "fringes" with waves of 350 to 400 metres have been obtained. Such interference is produced between waves travelling along the ground and those deviated by the ionised layer in the upper atmosphere. From the records the relative magnitudes of the effects of the atmospheric and ground waves and the resolving power of the equivalent optical system can be simply deduced.

2. The variations in resolving power throughout the night and daybreak periods have been studied and interpreted in terms of the variations of the equivalent height of the layer. The observations show that the equivalent height gradually increases throughout the night, but that about half an hour before sunrise its value falls rapidly. At about the same time the secondary maxima and minima on the main interference fringes disappear. As the morning proceeds, the atmospheric ray is gradually reduced in intensity and finally vanishes.

ÜBER DIE IONISATION DER ATMOSPHÄRE UND IHREN EINFLUSS AUF DIE AUSBREITUNG DER KURZEN ELEKTRISCHEN WELLEN DER DRAHTLOSEN TELEGRAPHIE (On the ionisation of the atmosphere and its influence on the propagation of the short electric waves of wireless telegraphy).—H. Lassen. (*Zeitschr. f. Hochfrequenz*, 28, 4, October, 1926, pp. 109-113; 28, 5, November, 1926, pp. 139-147.)

On the foundation of our present-day knowledge of the composition of the upper layers of the atmosphere and the ionisation of gases by ultra-violet light, attempt is made to describe the state of ionisation of the atmosphere, in so far as it is of significance for the propagation of the short waves of wireless telegraphy (less than 100 m.). A layer where ionisation is particularly marked is found to exist between 95 and 130 kilometres. This layer has no sharp boundary in the downwards direction—within the layer ionisation upwards at first increases and then decreases again. The propagation of short waves to great distances takes place for the most part in this layer, the effect of the ionic content expressing itself by a refraction of the wave, there being no substantial reflection. Damping is small. The ionised layer also remains in existence through the night, owing to the great rarefaction of the atmosphere at those altitudes, but the ionic concentration fluctuates with the twenty-four hours, accounting for the differences between day and night transmission. The remaining phenomena of short-wave transmission, skip distance, fading, etc., are also explained.

Further elucidation of the state of ionisation of the upper layers of the atmosphere is to be expected principally from practical measurements with waves of a few hundred metres (broadcast length), where it must be admitted, the relations are no longer quite so simple from the physical standpoint as with short waves.

LA LUNE INFLUENCE-T-ELLE LES TRANSMISSIONS RADIOÉLECTRIQUES ? (Does the moon affect radio transmission ?).—P. Vincent. (*L'Onde Electrique*, 5, 58, October, 1926, pp. 544-547.)

The author confirms the fact, that the movements and phases of the moon are not entirely unconnected with the variations in intensity of radio reception, from an examination of the graphs of the field produced at Meudon by the station Lafayette He finds that maximum intensity mostly occurs on days immediately following new phases of the moon, and seldom during the two or three days that precede them.

No attempt is made to discuss the different theories that might be put forward to explain this, *e.g.*, a disturbing influence of the moon on solar radiation ; or a direct influence of radiation emitted by the moon or reflected from it ; or an effect connected with the tides, themselves linked up with the movements of the moon.

COMMUNICATION TEST ON SHORT WAVES ACROSS THE PACIFIC.—T. Nakagami and T. Kawahara. (*Journ. Inst. Elect. Engineers Japan*, 460, November, 1926, pp. 1251-1264.)

The tests were made last spring between stations in Japan working on 21.5, 40.5, 43 and 115 metres respectively, and a ship travelling between Yokohama and San Francisco carrying a 500-watt transmitter working on 30 metres. The results showed :—

1. That a 40.5 m. wave may be used fairly satisfactorily for the whole range up to 8,400 km. at night.
2. That a 21.5 m. wave is much better than 40.5 for daytime transmission.
3. Skip distance phenomena are well exhibited by the audibility curves, and
   (*a*) the shorter the wave the greater the skip distance ;
   (*b*) the shorter wave skips farther at night than by day.
4. For a certain distance there is one wave that gives the same signal strength both by night and

by day. From the curves one obtains 21.5 m. for 3,100 km., 30 m. for 1,500 km., and 40.5 m. for 520 km. These data yield a curve showing the relation between distance and wavelength and thus the right wavelength to choose for a given distance—at this season of the year: in summer this wave would be shorter and in winter longer.

ELECTRIC WAVES AND THEIR PROPAGATION.—E. Rutherford. (*Nature*, 118, 4th December, 1926, pp. 809-811.)

Extract from the anniversary address delivered before the Royal Society on 30th November: a survey of the progress of our knowledge of the subject.

DIE WISSENSCHAFTLICHEN PROBLEME DES RUNDFUNKS (Scientific problems of broadcasting).—K. Wagner. (*Teleg. u. Fernspr. Techn.*, 15, pp. 76-78.)

Three principal problems are said to be awaiting solution: the determination of the laws of propagation of electromagnetic waves of different lengths, the measurement of atmospheric disturbances and their variation with place and time, and the investigation of the fluctuations of received signal strength.

INTEGRALS OF THE EQUATIONS OF ELECTRODYNAMICS, WITH AN APPLICATION TO THE ELECTRIC CONSTANTS OF A TRANSPARENT MEDIUM.—H. M. Macdonald. (*Proc. Royal Society*, 113, A764, pp. 237-253.)

EINIGE FOLGERUNGEN AUS DEN FELDGLEICHUNGEN DES SCHWINGENDEN DIPOLS (Some consequences of the field equations of the oscillating dipole).—F. Pollaczck. (*Elek. Nachr. Technik*, 3, 11, pp. 433-438.)

A mathematical discussion.

ELEKTROMAGNETISCHE SCHWINGUNGEN UND WELLEN IN FARADAYSCHER BETRACHTUNGSWEISE (Electromagnetic oscillations and waves from Faraday's view-point).—F. Kiebitz. (*Telefunken Zeitung*, 8, 43, October, 1926, pp. 19-24.)

A discussion of the phenomena on which wireless telegraphy is based showing that a representation of the phenomena in the dielectric can have advantages. The radiation of electromagnetic forces, electric oscillations and their damping are described without employing the notions of current, tension or resistance, whereby the way to the analytic treatment of these phenomena follows directly from Maxwell's laws. The propagation of electromagnetic waves appears as a most simple natural phenomenon. The oscillation in a conductor is represented as a disturbed electrodynamic phenomenon, the radiation being an imperfection of this disturbance. The damping in an oscillatory circuit is described by means of time values that are easily pictured.

MAGNETIC STORMS AND WIRELESS COMMUNICATION.—T. L. Eckersley. (*Nature*, 118, 4th December, 1926, pp. 803-804.)

In *Nature* of 6th November, p. 662, Sir Joseph Larmor suggests that the attenuation of the Canadian beam signals during magnetic storms is due to an incursion of electrons twisting the ray-paths out of regularity. Mr. T. L. Eckersley here states that the explanation that appeals to him is that ionic refraction is not the only factor determining long distance short-wave transmission, but that there is also the effect of energy absorption by collisions of electrons with molecules. The fact that the range of a station in summer and in low latitudes is less than that in winter and high altitudes, is part of a considerable body of evidence that absorption plays an important part in long distance short-wave transmission. It is shown why on theoretical grounds absorption would be expected to have an appreciable effect in transmission over distances greater than about 1,000 km.

At short distances the effect of increased bending, due to increased ionic density, is most apparent. The strength of local stations received in England was considerably augmented at times during the magnetic disturbances.

ATMOSPHERICS.

GLEICHZEITIGE LUFTSTÖRUNGEN IN DER DRAHTLOSEN TELEGRAPHIE (Simultaneous atmospherics in wireless telegraphy).—M. Bäumler. (*Elek. Nachr. Technik*, 3, 11, pp. 429-433.)

The author has already shown (*Jahrb. drahtl. Tel.*, 19, 2; 20, 6; 23, 1) that the range of atmospherics can be very great, disturbances having been simultaneously recorded at stations as far apart as Berlin and Rocky Point, 6,400 km. from one another. In this paper he describes his continued investigation of the subject with the co-operation of the Radio Corporation of America, employing the receiving stations at Koko Head (Oahu, Hawaii) and Marshall (California). A large number of corresponding disturbances were recorded at these stations, which are 3,900 km. apart, and isolated disturbances were found to occur simultaneously at distances of 10,000 to 12,000 km. The author applies the general propagation phenomena of electromagnetic waves to the propagation of atmospherics to explain the frequency of the occurrence of simultaneous disturbances, *i.e.*, atmospherics would be expected to travel better by night than by day, over sea than over land, and also to be considerably attenuated on passing from darkness to daylight or *vice versa*. The close correspondence between the atmospherics recorded at Koko Head and Marshall is attributed to both stations being in darkness at the time of the tests.

Specimens of recording strips at Koko Head, Marshall and Berlin are reproduced, showing the simultaneous occurrence of atmospherics at these places.

The causes of the disturbances are considered to be changes in the state of the electric field of the atmosphere or of the magnetic field of the earth, rearrangements in the earth's interior or phenomena of electrical equilibrium in the cosmos. Lightning discharges belong to changes in the state of the earth's electric field and the intense discharges in the tropics are regarded as a principal source of atmospherics.

LES PERTURBATIONS ORAGEUSES DU CHAMP ELECTRIQUE ET LEUR PROPAGATION À GRANDE DISTANCE.—P. Lejay. (*L'Onde Electrique*, 5, 59, November, 1926, pp. 557-576.)

The last three chapters of a paper read before the S.A.T.S.F., summarised in the preceding issue of these abstracts (*E.W. & W.E.*, p. 50, January, 1927).

PROPERTIES OF CIRCUITS.

OPERATION OF THERMIONIC VACUUM-TUBE CIRCUITS.—F. Llewellyn. (*Reprint B*-208, Bell Telephone Laboratories, Inc.)

General exact equations are derived for the output current when the valve is connected in circuits of any impedance and excited by any variable voltage. The method of derivation is illustrated in the special case where resistances only are considered, and the adaptation of complex impedance to use in non-linear equations is shown. Approximations that are allowable in various practical applications are indicated, and the equations are applied in some detail to grid-leak detectors, and in brief to other types of detectors, modulators, amplifiers and oscillators.

LES ANTENNES-FILTRES.—J. Plebauski. (*L'Onde Electrique*, 5, 58, October, 1926, pp. 532-544.)

It is shown that several antennæ can be combined by mutual coupling so that their energies add together for certain frequencies and subtract for others. They thus behave like the elements of a filter and furnish resonance curves that are almost rectangular with high efficiencies.

ÜBER DIE VERSTÄRKUNG VON IM HÖRBEREICH LIEGENDEN SCHWINGUNGEN MIT WIDERSTANDSVERSTÄRKERN (On the amplification of oscillations in the audible range with resistance amplifiers). — A. Forstmann. (*Zeitschr. f. Hochfrequenz*, 28, 5, pp. 156-161.)

Deduction and discussion of the relations for an amplifier with resistance capacity coupling whose distortion in a prescribed range of audible frequency does not exceed a given amount.

TRANSMISSION.

SOME NOTES ON DESIGN DETAILS OF A HIGH POWER RADIO TELEGRAPHIC TRANSMITTER USING THERMIONIC VALVES.—R. Hansford and H. Faulkner. (*E.W. & W.E.*, January, 1926, pp. 42-48.)

Abstract of a Paper read before the Wireless Section of the Institution of Electrical Engineers, on 1st December, 1926.

QUARTZ CRYSTALS AND THEIR PRACTICAL APPLICATION TO WIRELESS CIRCUITS.—A. Hinderlich. (*E.W. & W.E.*, January, 1927, pp. 29-41.)

A Paper read before the Radio Society of Great Britain, 24th November, 1926.

The phenomena of piezo-electric quartz are considered with special reference to radio transmitting stations.

ROHRENSENDER-SCHALTUNGEN, INSBESONDERE FÜR KURZE WELLEN (Valve transmitter circuit arrangements, especially for short waves).—W. Kummerer. (*Elek. Nachr. Technik*, 3, 11, pp. 408-414.)

A lecture given at the Düsseldorf meeting last September, dealing with the reaction that occurs between principal and modulating circuits in the case of externally modulated valve transmitters, and discussing various methods for eliminating it.

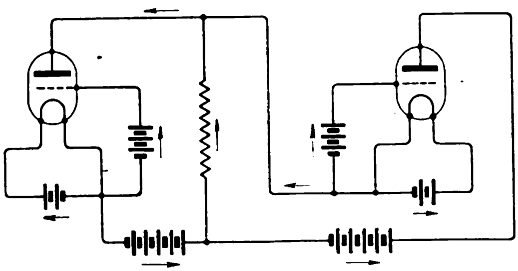
UN PROCÉDÉ SIMPLE DE MODULATION (A simple method of modulation).—G. Veyre. (*L'Onde Electrique*, 5, 58, October, 1926, pp. 547-553.)

A new method of modulation is given in which the oscillator and modulator have their plates in parallel, as in the continuous current system, but dispensing with the choke coil of that system by altering the connection of the two plates. The author describes the modulation as excellent and economical and gives some particulars of his station at Casablanca with the results obtained.

RECEPTION.

ALIMENTATION DES RÉCEPTEURS RADIOTÉLÉPHONIQUES PAR COURANT ALTERNATIF (Supplying radio-telephone receivers with alternating current).—H Niogret. (*L'Onde Electrique*, 5, 59, November, 1926, pp. 602-610.)

The special circuit arrangement considered consists essentially of two triodes with the spaces between filament and plate placed in series as shown in the figure below



This combination can be substituted for the triode in all its ordinary applications. It allows the employment of H.T. generators with varying voltage and, in certain cases, filament supply with alternating current.

COMPARISON DE LA DÉTECTION PAR LAMPE ET PAR GALÈNE (Comparison between valve and crystal detection).—Bertrand, Cayrel and Masselin. (*L'Onde Electrique*, 5, 59, November, 1926, pp. 593-601.)

The sensitivity of the valve is found to be very superior to that of galena for loud reception, appreciably superior for normal reception and practically equal for reception corresponding to the limit of audibility. The valve offers the further advantage of being able to supply several head-pieces connected in parallel without perceptible reduction of the sound strength. This double superiority of the valve is explained.

DISTORTION IN BROADCAST RECEIVERS. (*Electrical Review*, 24th December, 1926, pp. 1049-1050.)

Abstract of a paper read by Mr. J. A. Cooper before the Wireless Section of the South-Midland Centre of the Institution of Electrical Engineers on 6th December.

A FLOATING BEAT NOTE.—F. Anderson. (*Q.S.T.*, 10, 12, December, 1926, p. 18.

A circuit arrangement is given providing an automatic frequency change for superheterodynes, doing away at the same time with the troublesome double beat.

DEVISING A SHIELDED RECEIVER KIT.—M. Silver and K. Clough. (*Q.S.T.*, 10, 12, December, 1926, pp. 27-31.)

STATIONS: DESIGN AND OPERATION.

HAUPTFUNKSTELLE FÜR UNGARN IN SZÉKESFEHÉRVAR (High power station for Hungary at Stuhlweissenburg.) (*Telefunken Zeitung*, 8, pp. 57-63.)

Illustrated description of this station, about 60 km. to the south of Budapest, the transmitting equipment including an alternator of 50kW antenna output and a 10kW externally modulated valve oscillator. Reception takes place at Tarnok, about 20 km. from Budapest—where the central office is situated. Stations principally communicated with are Berlin, Paris, Pisa, Northolt, Cracow, Sofia, Barcelona and Fiume.

AERIALS AND RECEIVING APPARATUS AT THE NEW ST. ALBANS STATION.—L. Jones. (*Wireless World*, 8th December, 1926, pp. 761-764.)

DIRECTIONAL WIRELESS.

THE CHARACTERISTICS OF BEAM TRANSMITTING AERIALS.—J. Catterson-Smith. (*Journal of the Indian Institute of Science*, 9B, 2, pp. 9-19.)

The phases of the components of the radiated field of multiple aerial systems are considered and polar distribution diagrams plotted. The production of a single beam with minor secondary rays is dealt with by means of examples. Cylindrical parabolic and plane reflectors of the double grid type are contrasted and methods are considered of reducing dispersion in both vertical and horizontal planes.

STATIONARY AND ROTATING EQUISIGNAL BEACON. —W. Murphy and L. Wolfe. (*Soc. Auto. Engrs. Journal*, September, 1926, pp. 209-220.)

The equisignal method of airplane signalling consists in receiving signals, sent out by one or more transmitting stations, alternately on two loops, the planes of which differ by a certain angle. If the signals obtained on the two loops are equal in intensity, the bisector of the angle between the loops will correspond to the line of wave propagation.

In the development of the apparatus described in this paper use is made of the Bellini-Tosi antenna system and Kiebitz's idea of employing two directional antennæ, the planes, and therefore the directional effects, of which differ from one another by a certain angle and sending out the letter *n* (- .) in Morse code on one antenna and the letter *a* (. -) on the other (*Jahrb. drahtl. Tel.*, 15, 1920, p. 299). The paper shows how these two systems are combined to produce either rotating equisignals or fixed equisignals in any desired direction and is illustrated with charts, diagrams and photographs. Two practical examples of flights are given.

PROCÉDÉ ET APPAREIL POUR CALCULER RAPIDEMENT LE POINT EN RADIOGONIOMÉTRIE.—C. Ledoux. (*Comptes Rendus*, 183, 22, 29th November, 1926, pp. 1029-1030.)

On account of the small space, vibration, and quickness required, direction-finding in an aeroplane debars in practice methods with large maps, geometrical instructions, cumbersome abaci or numerical calculations. An instrument dispensing with these is described, giving results sufficiently accurate for aerial navigation.

RADIOGONIOMÈTRES ET RADIOPHARES À MAXIMUM ACCENTUÉ. — L. Bouthillon. (*Comptes Rendus*, 183, 21, 22nd November, 1926, pp. 955-957.)

A mathematical examination of the radiogoniometer problem considered identical with that of the rotating radio beacon.

NOTE SUR LE CALCUL DE LA COURBE DE DÉVIATION D'UN RADIOGONIOMÈTRE DE BORD SUR LES NAVIRES DE COMMERCE (Note on the calculation of the error curve of a radiogoniometer on mercantile ships). — M. Gouinet. (*L'Onde Electrique*, 5, 58, October, 1926, pp. 553-555.)

The author points out a small correction to be made in Mesny's formula for it to apply better to the radiogoniometer on large modern packet-boats.

VALVE DESIGN AND THERMIONICS.

ÜBER DIE VERWENDUNG DER ELEKTRONENRÖHRE ALS HOCHFREQUENZGENERATOR BEI ABWESENHEIT FREMDER HILFSSTROMQUELLEN (On the employment of the valve as high-frequency generator in the absence of outside sources of auxiliary current).—F. Müller. (*Arch. f. Elektrot.*, 17, 2, pp. 143-152.)

If in the working of an ordinary valve, the external electromotive forces in the form of heating and anode batteries are eliminated, there still remain the inner forces between hot filament on the one hand, and anode and grid on the other—due chiefly to the emission of thermo-electrons from the filament, which may be determined from the different electronic velocities.

In this article experiments are described which leave no doubt that the inner electromotive forces of a valve can serve for the generation of undamped oscillations. External electromotive forces are eliminated by using interrupted direct current instead of the usual sources of heating current. By means of a special rotating interrupter the filament is periodically heated and then connected to the anode with the source of current disconnected.

A current is thus produced in the anode (or grid) circuit due to the inner electromotive forces. These latter can assume values from one up to several volts with an internal resistance of some thousand ohms. If such an arrangement be completed with oscillatory circuits, oscillations will be generated whose maintenance is to be traced to the action of the electrons with the greatest heat velocities.

A thorough treatment of the problem could only be carried out with an extraneous source of heat of a non-electric nature, but the difficulties of such an experiment are very great owing to the simultaneous attainment of high temperatures and high vacua involving experimental conditions that are almost mutually exclusive.

MESSUNG GROSSER EMISSIONSSTRÖME AN SENDERÖHREN UND GLEICHRICHTERN (Measurement of large emission currents in transmitting valves and rectifiers.)—G. Jobst and K. Matthies. (*Telefunken Zeitung*, 8, 43, October, 1926, pp. 39-42.)

Two methods of measurement are described differing from the usual methods, in which grid is joined to anode and the anode connected to a positive direct tension, in that only short discharge impacts are employed. In the first method this is achieved by means of condenser discharges, and in the second method by means of alternating tension with or without an applied negative tension.

POSITIVE RAYS PRODUCED IN THERMIONIC VACUUM TUBES CONTAINING ALKALI-METAL VAPOURS.—H. Ives. (*Journ. Franklin Institute*, January, 1926, pp. 47-69.)

Description of experiments establishing the fact that it is possible to produce positive ions of the alkali metals—sodium, potassium, rubidium, and caesium—by allowing the alkali metal vapours to come in contact with a heated tungsten filament, and that the range of filament temperatures through which this phenomenon occurs is limited. The lower limit of temperature is set by the coating of the filament with a layer of alkali metal, and the upper limit (in so far as the production of positive ions *alone* is concerned) by the occurrence of the electron emission of the tungsten filament itself.

MEASUREMENTS AND STANDARDS.

RADIO FIELD-STRENGTH MEASURING SYSTEM.—H. Friis and E. Bruce. (*Reprint B-209*, Bell Telephone Laboratories.)

A paper dealing with a new system of measurement which has been used successfully at a frequency as high as 40 megacycles. The apparatus is a double-detector receiving set which is equipped with a calibrated intermediate frequency attenuator and a local signal comparison oscillator. The local signal is measured by means of the intermediate frequency detector, which is calibrated as a valve voltmeter.

THE PIEZO-ELECTRIC QUARTZ RESONATOR AND ITS EQUIVALENT ELECTRICAL CIRCUIT.—D. W. Dye. (*Proc. Physical Society, London*, 38, 5, pp. 399-458.)

The quartz piezo-electric resonator is examined experimentally and theoretically with special regard to an equivalent electrical system which can represent it.

It is shown that, as theoretically predicted by Butterworth, such a resonator can be represented by an inductance, a resistance and a capacity all in series. These are pictured as in parallel with another small condenser and the whole is in series with a third condenser, the additional condensers representing air-gaps. The equations for the current in an oscillating circuit, to which the resonator is attached, are developed and it is found that almost perfect agreement exists between the forms of current curve obtained theoretically and experimentally. This agreement is found to hold for longitudinal resonators of as low a frequency as 44,000 and for transverse resonators of as high a frequency as 15,000,000 periods per second.

It is next shown how the logarithmic decrement of the resonator may be obtained from a rectified line plotted from observations on the current in the oscillatory circuit as a function of frequency width across the crevasse which pierces the summit of the resonance curve.

The methods of analysis of the equivalent mesh into its components are next developed and it is shown that this analysis can be effected by carrying out a series of observations of the current at resonance when the air-gaps are varied by known amounts, or when the effective resistance of the oscillatory electrical circuit is given different known values.

The effects on frequency of response of variation of air-gap are studied and the difference between prediction and observation is discussed.

The temperature coefficient of frequency of a considerable variety of resonators is examined over a range of temperatures up to 40°C. It is found that very diverse results are obtained and probable explanations are offered.

The current taken by the quartz mesh is examined in some detail theoretically, and one or two experimental curves are given, together with a graphical method of deducing the curve of current from the constants of the quartz.

ÜBER PIEZO-ELEKTRISCHE KRISTALLE BEI HOCHFREQUENZ (On piezo-electric crystals at high-frequency). — A. Meissner. (*Elek. Nachr. Technik*, 3, 11, pp. 401-408.)

Lecture given to the Heinrich Hertz Society at the Düsseldorf meeting of German scientists, September, 1926: a general survey of the subject.

THE RESISTANCE OF HIGH-FREQUENCY CIRCUITS.—R. Ramsey. (*Phil. Mag.*, 2, 12, December, 1926, pp. 1213-1218.)

Although the resistance of a high-frequency circuit is apparently easy to determine, the separation of the resistance of the coil from that of the condenser is a difficult matter. It has been customary to consider the resistance of the condenser small enough to be neglected, so that the entire resistance of the circuit is ascribed to the coil.

The first attempt to measure the resistance of a condenser at high frequency was made by Weyl and Harris (*Proc. Inst. Radio Eng.*, 13, February,

1925, p. 109), and another method has been employed by Callis (*Phil. Mag.*, 1, February, 1926, p. 428). The results obtained in both cases are much larger than usually assumed, the resistance of a good variable condenser being found to vary from near one ohm at full capacity to fifteen or more at small capacity.

The writer tried to verify these results and describes his experiments here in detail. He found, however, that the resistance of a good radio condenser is not excessive and that the results of Weyl and Harris, and Callis are entirely too large. He shows that the probable explanation of their results is that an appreciable amount of energy is radiated from an ordinary circuit, *i.e.*, there is a certain amount of resistance in the circuit which cannot be ascribed to either the condenser or the coil.

TELEPHONE TRANSMITTER MODULATION MEASURED AT THE RECEIVING STATION.—L. B. Turner. (*E.W. & W.E.*, January, 1927, pp. 3-5.)

A NEW FORM OF FREQUENCY METER.—S. Chiba. (*Journ. Inst. Elect. Eng. of Japan*, No. 459, October, 1926, pp. 1121-1126.)

Description of a new form of frequency meter for the accurate measurement of acoustic frequencies. Circuit diagrams are shown, the frequencies being given by the approximate formulæ :

$$f = \frac{1}{2\pi\sqrt{nCM}} \text{ and } f = \frac{\sqrt{n}}{2\pi\sqrt{CM}}$$

where n is a constant.

By suitably choosing C, M, and the high resistance, the error can be reduced to less than 1 per cent. over the entire range of the frequency to be measured.

BERECHNUNG DER INDUKTIVITÄT VON SPULEN (Calculation of the inductance of coils).—K. Müller. (*Arch. f. Elektrot.*, 17, 3, pp. 336-353.)

A mathematical article in which, among other deductions, the correct formula is found for the mutual inductance of two cylindrical, single-layer, co-axial coils, differing from that of Kirchhoff, also there is given in closed form the radial and axial components of the magnetic field strength of a circular current, or a single-layer cylindrical coil, for a given point in space.

EIN NOMOGRAMM ZUR BERECHNUNG VON ZYLINDERSPULEN (A nomogram for the calculation of cylindrical coils).—E. Klotz. (*Telefunken Zeitung*, 8, pp. 42-44.)

THE RELATIVE IMPORTANCE OF LOSSES IN RADIO RECEIVING SYSTEMS. — W. HARPER. (*Q.S.T.*, 10, 12, December, 1926, pp. 21-24.)

A discussion of the subject of inductance standardisation.

MESSUNGEN AN DER BERGANTENNE AM HERZOGSTAND. (Measurements on the Herzogstand mountain antenna.)—O. Scheller. (*Elekt. Nachr. Technik*, 3, 11, pp. 423-425.)

The construction of this unique antenna has been described in *E.N.T.*, 3, 7, pp. 241-255. The present article gives details of the aerial and earth tests that were made when the antenna was under erection, the results of which determined the line that further construction should take. The first radiation measurements were made in 1920-1921 by Dr. Gerth, who describes them in the following article—*E.N.T.*, 3, 7, pp. 425-428.

LOUD-SPEAKER CHARACTERISTICS. — H. Krönke (*Wireless World*, 15th December, 1926, pp. 805-807.)

Description of a new method of measurement developed by Dr. Erwin Meyer.

THE DELINEATION OF ALTERNATING CURRENT WAVE FORMS.—H. A. Thomas. (*E.W. & W.E.*, January, 1927, pp. 15-23.)

SUBSIDIARY EQUIPMENT AND MATERIALS.

THE HISTORY AND DEVELOPMENT OF THE TELEPHONE.—Sir Oliver Lodge. (*Journ. Inst. Elect. Engrs.*, 64, pp. 1098-1114.)

Lecture delivered before the Institution, 24th June, 1926, on the occasion of the jubilee of the telephone, including a section on wireless telephony.

AUFNAHME-MIKROPHONE FÜR DEN RUNDFUNK (Microphones for broadcast transmission).—F. Weichart. (*Zeitschrift f. Hochfrequenz*, 28, 4, pp. 120-128.)

A discussion of microphones divided into the following six groups :—

Contact microphones.
Capacitative microphones.
Electromagnetic and electrodynamic microphones.
Gas microphones.
Thermo-microphones.
Crystal microphones.

ON THE CONDENSER-TELEPHONE.—B. Cohen. (*Phil. Mag.*, 2, 12, December, 1926, pp. 1271-1272.)

A letter referring to Dr. Green's paper (*Phil. Mag.*, 2, 9, September, 1926), in which the results at first sight are somewhat perplexing, and pointing out that the paper really deals with the operation of a condenser-telephone with a special and very unsuitable form of coupling so far as low capacity types of instrument are concerned.

A BREAK-IN RELAY.—M. Brainard. (*Q.S.T.*, 10, 12, December, 1926, pp. 34-36.)

A REVOLUTIONARY DEVELOPMENT IN MICA INSULATION.—L. Barringer. (*General Electric Review*, 29, 11, November, 1926, pp. 757-762.)

Account of a new resin " Glyptal " which is very superior to shellac for mica insulation.

GENERAL PHYSICAL ARTICLES.

OPTIQUE ET RADIO ELECTRICITÉ (Optics and Wireless).—L. Bouthillon. (*L'Onde Electrique*, 5, 59, November, 1926, pp. 577-592.)

In a first part of the article (*L'Onde Electrique*, July, 1925) radio problems are shown to have their

optical analogues: directional frames are compared with Fresnel's mirrors, curtain antennæ with illuminated slits, and Zenneck's wave with that of Brewster.

In this second part, the author investigates the wireless equivalents of elliptical, parabolic and circular mirrors, and some simple optical systems.

Sur les Variations des Propriétés Optiques du Quartz Piézo-Electrique Soumis à des Courants de Haute Fréquence (On the variations of the optical properties of piezo-electric quartz subjected to high-frequency currents).—E. Taivil. (*Comptes Rendus*, 183; 6th December, 1926, pp. 1099-1101.)

Preliminary account of an optical phenomenon which may be of service for oscillographs and light modulators for phototelegraphy and television.

A Critical Résumé of Recent Work on Dielectrics. (*Journ. Inst. Elect. Engineers*, 64, November, 1926, pp. 1152-1190.)

Report prepared by Mr. Hartshorn at the National Physical Laboratory and received from the British Electrical and Allied Industries Research Association: a critical review of modern work and theories upon the subject of dielectric phenomena, extending over the past ten years.

Phase Difference in Dielectrics.—J. Whitehead. (*Journ. Amer. Inst. Elect. Engineers*, 45, 12, December, 1926, pp. 1225-1228.)

A brief description of the origins and causes of phase difference in dielectrics.

A Thermionic Theory of the Electrical Conductivity of Dielectrics.—H. Saegusa. (*Journ. Inst. Elect. Inst. Japan*, No. 460, November, 1926, pp. 1284-1291.)

An expression is obtained for electrical conductivity as a function of temperature and material constants. The natural frequencies of quartz plates are also deduced, the values falling within the range of those actually observed.

High Frequency Rays of Cosmic Origin III. Measurements in Snow-fed Lakes at High Altitudes.—R. Millikan and G. Cameron. (*Physical Review*, 28, 5, November, 1926, pp. 851-868.)

Experiments are described which provide new evidence for the existence of very hard etherial rays of cosmic origin entering the earth uniformly from all directions. The evidence points to the spectral distribution of these rays, the lower end of the absorption curve requiring a coefficient of .18 per metre of water and the upper end a coefficient of .30 per metre of water. These coefficients correspond to frequencies fifty times those of ordinary gamma rays. With regard to the origin of cosmic rays, it is concluded that these rays do not result from the union of protons with negative electrons, but that they are due to nuclear changes of about one-thirtieth the energy corresponding to such union taking place throughout the depths of the universe.

Recent Developments of Cosmical Physics.—J. H. Jeans. (*Supplement to Nature*, 118, 4th December, 1926, pp. 29-40.)

A lecture delivered at University College, London, on 9th November, 1926.

In the section on highly-penetrating radiation Dr. Jeans shows that "we should expect the atmospheres of the stars, sun, and earth, and even the solid body of the earth, to be under continual bombardment by highly-penetrating radiation of nebular origin."

Properties of High Frequency Radiations.—J. Gray. (*Nature*, 118, 4th December, 1926, pp. 801-802.)

Statements are made tending to show that no conclusive evidence has been found for the view that the radiation causing the ionisation in closed vessels is a cosmic radiation of high frequency.

Luminescence from Solid Nitrogen, and the Auroral Spectrum.—L. Vegard. (*Nature*, 118, 4th December, 1926, p. 801.)

A letter in reply to statements by Prof. McLennan and his collaborators regarding the origin of the auroral spectrum, published in *Nature* of 18th and 25th September.

The writer states that the identification of the auroral line with an oxygen line, observed by McLennan, seems to be in contradiction with facts and maintains that his continued experiments with solid nitrogen show that solid nitrogen gives the whole typical auroral spectrum from red to ultraviolet.

The Aurora Borealis as Observed from Norway. (*Nature*, 118, 4th December, 1926, pp. 797-799.)

A review by Prof. S. Chapman of Prof. Størmer's work giving the results of measurements obtained from photographs of auroræ occurring in Norway between 1911 and 1922.

Power of Fundamental Speech Sounds.—C. Sacia and C. Beck. (*Reprint B-206*, Bell Telephone Laboratories.)

Description of a continuation of the work on speech power by means of oscillographic studies of vowels, semi-vowels and consonants. A previous paper considered the characteristics of a few individual sounds from the power standpoint, but the principal emphasis was placed upon speech as a whole. In this later analysis sounds are considered individually on the basis of instantaneous and mean power. A practical application of the results is suggested.

A Possible Connection between the Wave-Theory of Matter and Electro-Magnetism.—H. Bateman. (*Nature*, 118, 11th December, 1926, pp. 839-840.)

Theories of a New Solid Junction Rectifier.—L. Grondahl. (*Science*, 64, pp. 306-308.)

Preliminary announcement of a new type of rectifier, consisting of a disc of copper with a coating of oxide formed on its surface. Under suitable conditions, current flows more readily from the

oxide to the copper than in the reverse direction. Explanations of contact rectification usually given, such as electrolysis and thermo-electricity, are shown to be untenable for this new electronic solid-junction rectifier. The seat of rectification is apparently restricted to the layer near the junction between the copper and the compound formed on it.

THE IONISATION OF ATOMS BY ELECTRON IMPACT.—E. Lawrence. (*Physical Review*, 28, 5, November, 1926, pp. 947-961.)

Precision in critical potential measurements in the past has been seriously limited by the lack of homogeneity in velocities of the electrons. This source of error has been eliminated by separating out magnetically electrons of definite velocities. The electron beams used in the present experiments were not characterised by great homogeneity in velocities but by sharp upper limits to their velocity distributions. Critical potentials were measured as the differences between two retarding potentials —the smallest retarding potential preventing the entrance of the electrons into the Faraday cylinder type of ionisation chamber and the largest retarding potential for which the effect under investigation is observed—thereby eliminating errors due to contact electromotive forces.

ON THE EXCITATION OF POLARISED LIGHT BY ELECTRON IMPACT.—H. Skinner. (*Proc. Roy. Soc.*, 112, A762, pp. 642-660.)

An electron tube producing an intense uni-directional stream of electrons of slow speed is used for the excitation of the mercury spectrum, and polarisation measurements are made on the light emitted from the tube in a direction at right angles to the direction of the stream. It is found that with an electron speed corresponding to 20 volts many of the mercury lines are partially plane-polarised, most with direction of the maximum electric vector parallel to the stream, but some in the perpendicular direction.

ON THE TOTAL PHOTO-ELECTRIC EMISSION OF ELECTRONS FROM METALS AS A FUNCTION OF TEMPERATURE OF THE EXCITING RADIATION.—S. Roy. (*Proc. Roy. Soc.*, 112, A762, pp. 599-630.)

MISCELLANEOUS.

TRANSATLANTIC WIRELESS. (*Electrician*, 97, 17th December, 1926, p. 696.)

Mr. Marconi describes his experiences 25 years ago, when on 12th December, 1901, he succeeded in establishing wireless communication between Poldhu, Cornwall, and St. John's, Newfoundland, showing photographs of the original plant and equipment. With regard to the next 25 years, Mr. Marconi says there will probably be almost as great a development in means of obtaining directional wireless transmission and reception as there has been in other directions during the last 25 years, also that there is a possibility that the transmission of power over moderate distances may be developed and that television will become an actuality.

CARRIER CURRENT COMMUNICATION OVER TRANSMISSION LINES.—E. Carter. (*General Electric Review*, 29, 12, December, 1926, pp. 833-845.)

An article dealing with the requirements to be fulfilled, single-frequency duplex equipment, inter-system communication, amount of carrier energy required, and operation.

BILDTELEGRAPHIC UND SCHNELLTELEGRAPHIC MIT DER KAROLUS-ZELLE (Picture and high-speed telegraphy with the Karolus cell).—F. Schröter. (*Telefunken Zeitung*, 8, 43, October, 1926, pp. 7-13.)

RADIO STATISTICS. (*Scientific American*, December, 1926, p. 458.)

The data collected from a two-year survey of broadcasting in the United States revealed the fact that of the 1,424 stations licensed by the Government since November, 1920, 878, or 62 per cent., have ceased to function. The two principal reasons for the discontinuance of broadcasting are inability to finance, 45 per cent., and service unsatisfactory as compared with the larger competing stations, 17 per cent.

THE B.E.S.A. GLOSSARY.—G. W. O. Howe. (*Electrical Review*, 10th December, 1926, p. 979.)

A letter in answer to those of Mr. Fawcett and Prof. Fortescue appearing in the *Review* of 12th and 19th November respectively. Referring to the former, Prof. Howe explains that "electromotive force" and "magnetomotive force" are misnomers and not forces at all; and replying to the latter letter, he distinguishes between B and H and goes on to show that H has real existence. In the *Review* of 24th December Prof. Fortescue writes that this does not answer his question, his inquiry as to the objective difference between a field strength and a flux density applying to either the electric or the magnetic field.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

Effective Resistance of Inductance Coils.

To the Editor, E.W. & W.E.

SIR,—In connection with the masterly series of articles on the Effective Resistance of Inductance Coils at Radio Frequency in *E.W. & W.E.* and the applications of the same principles to low loss coil design given in the *Wireless World*, the following may be of interest to some of the many readers, who, like the present writer, must have been impressed and highly appreciative of the brilliant manner in which Mr. Butterworth handled an extremely complex subject.

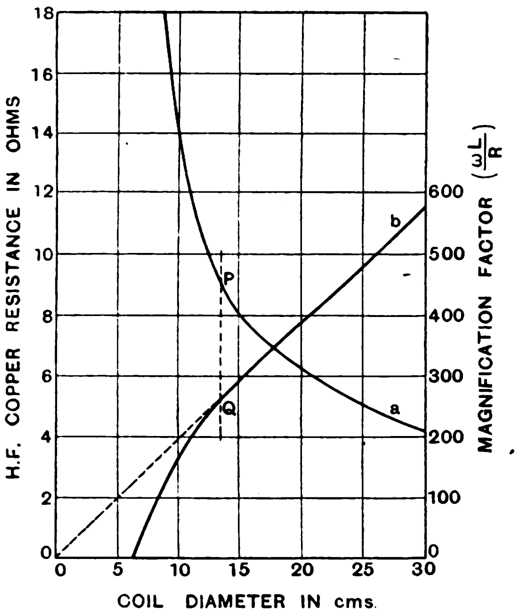


Fig. 1.

Mr. Butterworth, very practically, concerns himself chiefly with coils of quite small dimensions, and while these coils are all that can be desired for valve apparatus, particularly where appreciable reaction is used, it seems that many people would not be concerned with any reasonable increase of size or cost to obtain a very efficient coil for, say, the reception of Daventry with a crystal set. With the limitation of size he imposes, Mr. Butterworth advises the use of a multilayer coil for this wavelength as it can be made more efficient than a single layer coil, but if the size is not limited, the single layer coil with a winding length equal to its radius is, according to his tables, undoubtedly the best shape.

The following are particulars of a series of coils for this wavelength, *i.e.*, having an inductance of 2,000 microhenries, which are single layer and have the ratio of length to diameter 0.5.

The diameter is progressively increased up to 30 cms., and the number of turns and the wire diameter are adjusted for best efficiency in each case.

TABLE I.

SOLID WIRE COILS.

Dia. (cms.).	No. of turns.	Wire.	R_c (ohms).	$M = \frac{\omega L}{R_c}$
7.5	161	38 D.S.C.	34.55	68*
10.5	139	32 D.S.C.	13.92	169*
12.5	125	28 D.S.C.	9.85	239*
15.0	114	23 D.S.C.	7.96	295
17.5	105	22 D.S.C.	7.05	333
20.0	98	21 D.S.C.	6.15	382
22.5	93	20 D.C.C.	5.45	432
25.0	88	19 D.C.C.	5.00	470
27.5	84	18 D.C.C.	4.54	518
30.0	80	17 D.C.C.	4.11	572
			(*a*)	(*b*)

* Best wire diameter not possible, but nearest used.

The results are also plotted in Fig. 1.

It is seen that the last coil has a magnification factor about three times greater than the average good commercial coil of this inductance.

It is interesting to notice how sharply the resistance curve rises as soon as it is not possible to use the optimum wire diameter.

The values, of course, neglect other losses in the coil, but as Mr. Butterworth points out, these are practically negligible with reasonable design.

Another interesting point in the graph is that Curve *b* (magnification factors) is a straight line passing through the origin (the dotted portion showing continuation of curve if it were possible to use optimum wire diameter in each case), thus *showing that the best resistance is inversely proportional to the diameter*, as Mr. Butterworth states would be so for high frequency.

The resistances of coils were also calculated using stranded wire, this being only possible in the case of the last five coils.

The particulars are given in Table II.

TABLE II.

$L = 2{,}000\mu$H. $b/D = 0.5$.

STRANDED WIRE COILS.

Dia. (cms.).	No. of turns.	Wire.	R_c (ohms).	$M = \frac{\omega L}{R_c}$
20.0	98	9/34	4.23	555
22.5	93	9/34	4.20	560
25.0	88	9/34	4.19	565
27.5	84	27/36	2.58	910
30.0	80	27/36	2.50	940

The D.C. resistances were calculated from tables neglecting twist, so will be slightly larger.

It will be seen that the extremely low figure of 1.25 ohms per millihenry is obtainable in the last case.

The writer hopes to verify these resistances experimentally and to see whether results in the case of crystal reception of Daventry justify the large space occupied by these coils.

JOHN L. SMITH.

Mathematics for Wireless Amateurs.

To the Editor, E.W. & W.E.

SIR,—As a reader of above since its commencement as a periodical, may I offer my thanks for the excellent articles on Mathematics contained therein. As an enthusiastic, albeit a humble, student, of physical science, and particularly "Radiations," I find Mr. Colebrook's articles particularly useful as a "refresher course," and I trust that he will be allowed to take us through the "Calculus." His treatment, judging from the present instalments, would promise a treat to which I am looking forward.

Note.—I do not find answers to given examples in previous numbers. Is it intended to give these? I am also glad to note the inclusion of notes on experiments, such as the introduction of sodium and potassium into discharge tubes. To emulate this is going to give me many hours' pleasure. Let's have some more of this, please! In conclusion may I express the hope of some articles on the "Physics" of radiations as distinct from engineering.

I realise that perhaps I am but one voice in thousands.

J. G. CLAYTON.

Plate-current, Plate-voltage, Characteristics.

To the Editor, E.W. & W.E.

SIR,—I have been much interested in the controversy following my original letter on the above subject and Mr. Green's reply, with which I agree entirely. Of course, I only quoted the Krönke article on resistance coupling as a case in which existing views had been shown to be erroneous and not as a case of transformer coupling!

I noted his remarks on Mr. P. W. Willans' paper, but must comment that this deals with practical examples where, as I remarked, intercapacities and leakages come in and upset one's theory. Also, as Mr. Willans implies, he sacrifices the most "freaky," and therefore greatest response, curve for a flat-topped curve much better for music reproduction. (See in this connection Mr. Kirke's paper, June issue, p. 358.)

Mr. Fowler Clark takes exception to two of my statements in his letter but takes them out of their context, thereby altering their import considerably, though they are still true even when so ill-used!

To meet him on his own ground, I must first point out that R and X are not necessarily connected by any such law of equal variation; in fact, they can be almost independent variables. Taking any particular values of R and X, it is undoubtedly true that

$$I^2R,\ I^2\sqrt{\frac{1}{R^2+X^2}}\quad\text{and}\quad I^2X$$

all reach maximum values together but it is a colossal howler to say that this happens when $\sqrt{R^2+X^2}=\rho$ (valve A.C. resistance). Keeping R and X constant I can always be increased by reducing ρ the internal A.C. resistance (*e.g.*, by turning the valve filament up and I tends to its maximum as $\sqrt{R^2+X^2}/\rho$ tends to infinity.

I must point out that there are two points on *every* transformer curve at which its impedance is matched to any valve, but that in all cases the "response" curve, *i.e.*, curve of overall amplification of valve and transformer is nearly at its minima at these; the highest amplifications are at points where the transformer impedance is ten or a hundred times as great as the valve A.C. resistance.

As Mr. Fowler Clark most truly remarks, there is a very cogent reason to have one of these points low in the audio scale—no one would buy a transformer which was matched on, say, the middle *G*, because its overall performance would be so poor—some of the early cheap transformers came near to this.

Anyone knows that to reduce amplification one turns a valve filament down—*i.e.*, raises its A.C. resistance more nearly to the impedance of the associated transformer. I fear that Mr. Fowler Clark rushed into the fray guided by his preconceptions and is trying to fit arguments to them without going to facts sufficiently.

If, however, the standard expression for overall amplification is taken

$$\left(\mu\sigma\sqrt{\frac{X^2}{X^2+(R+\rho)^2}}\right)$$

where μ, σ, X and R have their usual significance and $\rho=$ internal A.C. resistance of the valve the following facts are evident:—

1. The smaller R and/or ρ are in proportion to X the nearer the expression is to its maximum.

2. Taking $\left\{\frac{\sqrt{X^2+R^2}}{\rho}\right\}$ as the independent variable the overall amplification becomes a maximum as $\frac{\rho}{\sqrt{X^2+R^2}}$ tends to 0.

I must therefore reiterate my original point that *theoretically* one must increase the ratio of the transformer impedance to the valve internal A.C. resistance as much as possible.

How does practice modify this? Mr. Willans shows us in the July issue.

We want not only large amplification, but a nice flat-topped curve. This is gained by picking a σ to suit the valve and although ultimately the impedance ratio must yield partially to space considerations, intercapacities and other practical points—still it is right to say that the main law holds good that the transformer should be of the utmost possible impedance and not of matched impedance except in the one case of power output to a loud-speaker. One big firm quoted by Mr. Fowler certainly agrees with me.

Messrs. C. Holt Smith and Albert Hall gave different angles to the discussion and Mr. Albert Hall in particular gave some valuable practical measurements in support of my views and quotes Mr. Dye's paper very appositely. He has, in fact, stated my case far better than I did myself.

I should like to thank both critics and apologists for some extremely interesting views.

I. A. J. DUFF, B.A., A.M.Inst.C.E.

Manchester.

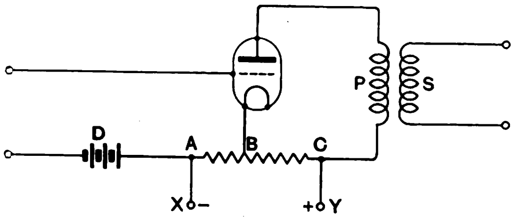
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each.

VALVE CIRCUITS SUPPLIED FROM MAINS.

(*Application date, 15th August, 1925. No. 261,110.*)

Many circuits have been devised for smoothing mains supply for use with valve circuits, but the accompanying invention, due to G. M. Wright, gives details of a circuital arrangement wherein any fluctuations which may arise are substantially balanced out. The specification gives one or two examples of the arrangement for various methods of valve coupling. The circuit is comparable with an arrangement which is used for determining the amplification factor of a valve, and, in fact, is somewhat similar. The invention consists in shunting the anode supply with a fixed resistance,

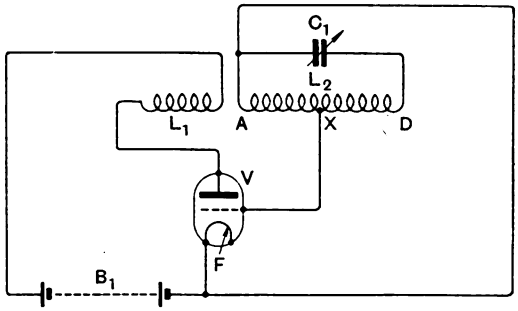


the filament connection of the valve system being made to a tapping on the resistance. The tapping point is so arranged that any variation of potentials in the grid circuit are balanced by proportionately opposite variation of potential in the anode circuit, thereby maintaining a substantially constant output. The accompanying diagram illustrates the invention as applied to a transformer-coupled valve. The anode circuit of the valve *V* contains the primary winding *P* of a transformer *PS*. The high tension supply *XY* is shunted by a resistance *ABC*. The grid circuit or input circuit of the valve is connected, not between the grid and filament, as is usual, but between the grid and the negative high tension terminal, *i.e.*, the end *A* of the resistance *ABC*, the filament connection being taken at *B*. Any variation in anode voltage supply will cause a fall of potential along the resistance *ABC*. A certain voltage will then be set up across the resistance *AB*, which will be communicated to the grid circuit of the valve, causing a corresponding magnified voltage to be produced in the anode circuit of the valve. Similarly, however, a voltage will be set up across the resistance *BC* which will be introduced into the anode circuit, since the resistance *BC* comprises part of the anode circuit. This voltage, however, will be opposite in sense to that produced by the magnified voltage across the resistance *AB*. Hence it follows that if the resistance *BC* is equal to the resistance *AB* multiplied by the amplification factor of the valve, the two voltages introduced into the anode circuit will be opposite and equal. The resistance *AB BC* is arranged in this proportion. A bias battery is shown at *D* for the purpose of balancing the steady potential drop across the resistance *AB*. The specification also describes the invention as applied to resistance-coupled valves, and indicates the manner in which the proportions of the resistance are determined.

FREQUENCY STABILISATION.

(*Application date, 13th November, 1925. No. 261,905.*)

It is essential that the constants of a wavemeter shall not vary, but this is liable to occur if the valve with which the instrument has been originally calibrated is substituted by another. Although valves of the same type have substantially similar characteristics one cannot really depend upon the input capacity, for example, remaining the same for all valves of the same type. A wavemeter circuit which overcomes this difficulty is described by Lt.-Col. K. E. Edgeworth, D.S.O., M.C., in the



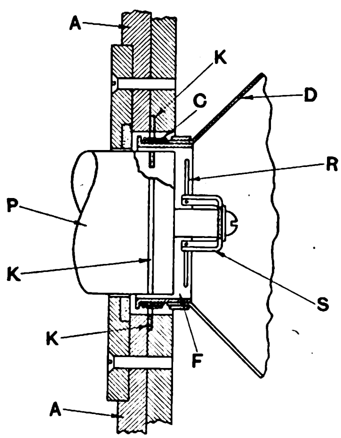
above British Patent. One arrangement, utilising a tuned grid circuit, is shown in the accompanying illustration. A valve *V* is provided with a reaction coil L_1 and the usual anode battery B_1. This is coupled to an inductance L_2 tuned by a variable capacity C_1. One end *A* of the inductance L_2 is connected to the filament *F*, this end being nearest to the reaction coil L_1. Instead of connecting the free end *D* of the tuned circuit directly to the grid, the grid connection is taken to a tapping *X* along the inductance L_2 so that only a few turns are connected between the grid and the filament. Variation of inter-electrode valve capacity under these conditions does not affect the frequency of the tuned circuit L_2 C_1 to such an extent as it would if the grid connection were taken at *D*. The reason for this should be obvious, of course, and is due to the fact that if any valve having a self-capacity higher than that of the original valve is used, the increased grid-filament capacity will only be in shunt to a few turns of the inductance L_2, and,

accordingly, the frequency of the circuit $L_2 C_1$ will only be lowered by an almost imperceptible amount, depending, of course, upon the ratio of the turns in circuit to the total turns of the inductance.

A MODIFIED COIL DRIVE.

(*Convention date* (*U.S.A.*), *20th April*, 1925. *No.* 250,931.)

Readers are no doubt familiar with the patent specifications relating to the Rice-Kellogg type of loud-speaker. A modified form of coil drive is described by C. W. Rice in the above British Patent.

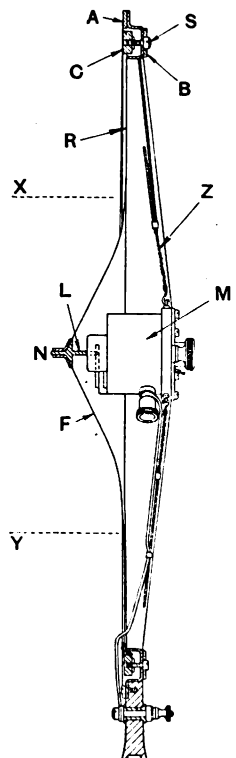


The type of loud-speaker referred to, of course, is that comprising a diaphragm attached to a light, rigid, moving coil, which is in an annular gap of a very powerful magnetic system. The speech currents are applied to the moving coil in which they create a field, cutting that due to the electro-magnet. Since the electro-magnet is fixed the force between the two fields causes the moving coil to be displaced, thereby energising the diaphragm. The specification states that the impedance of the moving coil is determined partly by its ohmic resistance, and partly by its reactance. At very low frequencies the impedance is due almost entirely to the ohmic resistance, whereas at higher frequencies the reactive component may predominate. This may, however, give rise to unequal response over the frequency range, and the object of the invention is to flatten out the response curve, which is accomplished by associating the moving coil with short-circuited turns or rings of copper of considerable dimensions located in the pole pieces, these copper rings acting somewhat in the manner of a short-circuited secondary winding of a transformer with reference to the moving coil. The accompanying illustration shows one method of arranging the invention, where a diaphragm D, the edge of which is not shown, is fixed to a light coil C wound on a cylindrical former F joined to the truncated portion of the conical diaphragm D. The moving coil C is in the air gap between the pole pieces comprising a cylindrical pole P and an annular pole A. The remaining portion of the magnetic system is not shown for the sake of clearness. The coil C is prevented from touching the central pole piece P by means of supports in the form of light rods R fixed to a spider S screwed to the end of the pole piece P. The free edge of the conical diaphragm D is also supported by thin leather, rubber, silk, or other suitable material. Two copper rings K are respectively embedded in the two pole pieces, that is, the central pole piece P and the annular built-up pole piece A. It will be obvious that lines of force from the coil C will cut the two rings K, which since they are closed circuits, will act as short-circuited secondary windings, thereby considerably lowering the impedance of the coil, which will not tend to increase so rapidly as the frequency of the applied voltage is raised. In this manner a more even response is obtained.

A CONE TYPE DIAPHRAGM.

(*Application dates*, *30th April*, *and 22nd June*, 1925. *No.* 257,317.)

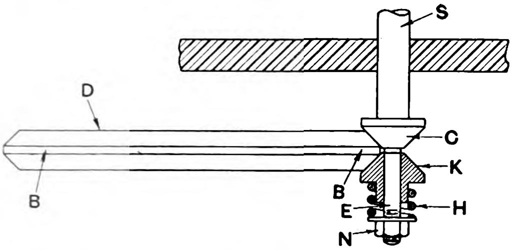
Another form of cone type diaphragm is described in the above British Patent Specification by N. W. McLachlan. Essentially the diaphragm comprises a combination of a cone and a ring, the two being integral and made of one piece of fabric, which is stiffened by treating with " dope " or celluloid varnish. The varnish is applied first on one side and allowed to dry, and then on the other, the process being repeated until sufficient strength is obtained. The edge of the diaphragm is held in a channel section, consisting of two rings A and B, variation of tension being obtained by means of another ring C, which is adjusted through the back of the channel section by means of screws S arranged round the periphery. The apex of the cone N is driven by a link L attached to a magnetic system M. This is supported by means of springs Z, which are attached to the metal ring supporting the diaphragm. The specification mentions that other material may be used for the supporting rings, and may have effect upon the tonal qualities of the loud speaker.



AN INGENIOUS DRIVE.

(*Application date, 19th August, 1925. No. 261,476.*)

In order to overcome the necessity for accurate assembly of a driving mechanism, such as a slow motion device for a variable condenser, a rather ingenious form of drive is described by H. J. Gowring and the Western Electric Company, Limited, in the above British Patent. One arrangement of the invention is shown in the accompanying illustration, where a disc *D*, mounted on a shaft, not shown, has to be driven from a shaft *S*. The edge of the disc is bevelled as shown at *B*. The shaft *S* is provided with a cone-shaped member *C*, while an extension of the shaft *S* is screwed and carries a nut *N* and a helical spring *H*. The helical spring *H* engages another cone *K*, shown in cross section, which is free to move on the extension *E* of the shaft *S*. The spring *H* exerts sufficient force upon the movable cone *K* to grip the bevelled edge of the disc firmly between the two cones *C* and *K*. Rotation of the shaft causes the two surfaces of the cones *C* and *K* to co-operate with the bevelled

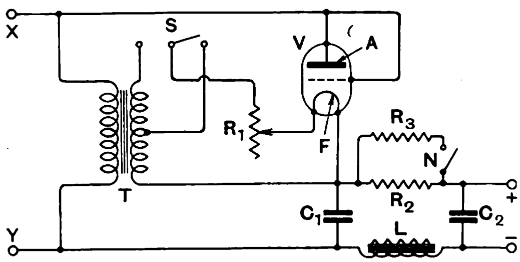


edge of the disc, thereby enabling the cone *C* to drive the disc. It will be obvious that owing to the nature of the drive a certain amount of flexibility is imparted to the system, thus obviating the necessity of the accurate alignment and disposition of the shaft *S* with respect to the disc *D*.

ANOTHER MAINS UNIT.

(*Application date, 7th September, 1925. No. 262,190.*)

The construction of the mains unit which embodies a particular form of smoothing circuit and special arrangement for the rectifying valve is described in the above British Patent by S. G. Thaine. The circuit which is employed is shown in the accompanying illustration. The alternating current supply is shown at *X* and *Y*, where it is taken direct to the anode *A* of the rectifying valve. This is shown as a three-electrode valve with the grid joined to the anode. A transformer *T* provides the heating current for the filament *F* of the valve *V*, while a variable resistance R_1 controls the filament current. The transformer is provided with a two-way switch *S* which connects the filament to either of two tappings. This enables the device to be used with small receiving valves having either bright or dull emitting filaments. The smoothing circuit is rather unusual, and comprises two condensers C_1 and C_2 on either side of a combination of resistances and a choke. The negative wire contains a choke *L* between the two condensers C_1 and C_2, while the positive lead contains resistances R_2 and R_3, the switch *N* being

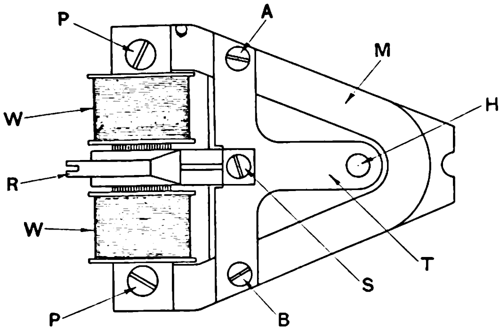


provided for connecting the resistances in parallel. The specification states that the choke may be of the order of 51 henries, and the resistance R_3 may be about 100,000 ohms, and the resistance R_2 about 9,000 ohms.

REED MOUNTING.

(*Application date, 19th September, 1925. No. 261,506.*)

A method of mounting a reed for the purpose of driving the diaphragm of a loud-speaker is described by S. G. Brown in the above British patent. The magnetic system of the loud-speaker movement comprises a V-shaped magnet *M* with laminated pole pieces *P*, which are screwed on to the ends of the V-shaped magnet. The two pole pieces carry windings *W*, a small gap, of course, existing between the ends of the pole pieces *P*. The reed *R* which drives the diaphragm is mounted in the following manner: The arms of the V-shaped magnet support the two ends *A* and *B* of a T-shaped member *T*, the reed being fixed to the middle



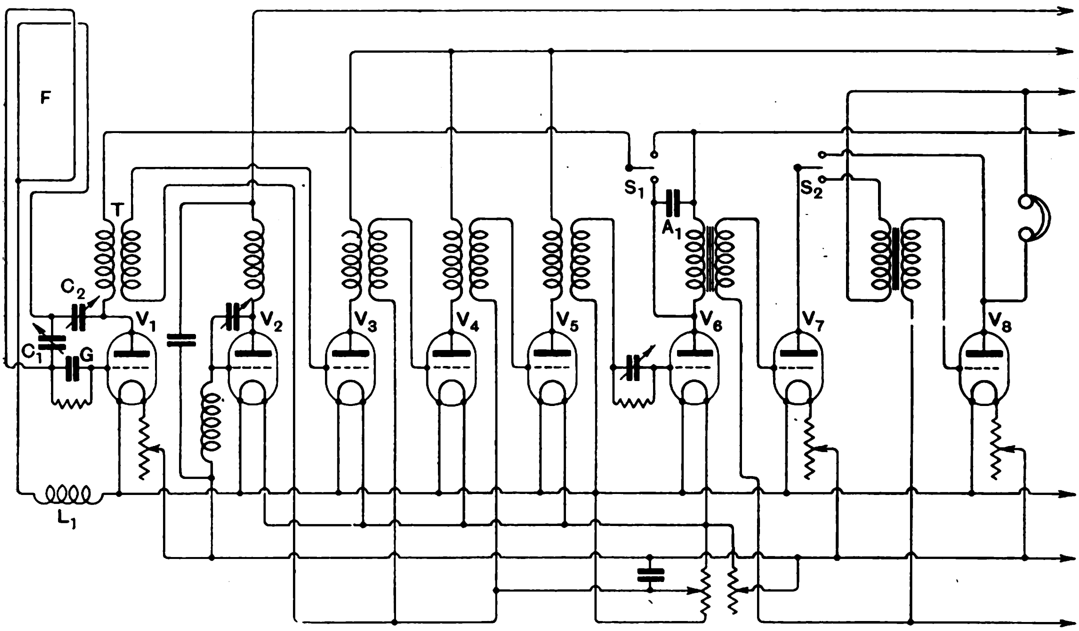
of the horizontal portion of the T-shaped member by a screw *S*. The remaining portion of the T-shaped member is provided with a hole *H* through which a screw (not shown) provided with a flanged portion working against a helical spring can pass.

Thus it will be seen that as the screwed arrangement working through the hole H is rotated it will cause the T-shaped member (which is of non-magnetic material) to move up and down, thereby imparting to the reed a similar motion. In this manner the distance between the reed and the pole pieces can be conveniently controlled.

A MULTI-VALVE RECEIVER.

(*Application date, 19th October*, 1925. *No.* 261,893.)

S. L. Forbes describes in the above British Patent a receiving system which can be used either as a supersonic receiver or a "straight" circuit. The complete circuital arrangement is shown in the accompanying illustration, although only some of the anode of the valve V_1 through a condenser C_2. The centre tap is taken to the filaments through an inductance L_1. The valve V_2 is arranged as a local oscillator for heterodyne reception either at supersonic frequency, or-audible frequency if desired. The anode circuit of the valve V_1 contains a long wave selector circuit in the form of a transformer T. A switch S_1 enables the anode circuit of the valve V_1 to be connected either to the high tension supply direct, or through a low frequency transformer A_1. Valves V_3, V_4 and V_5 comprise an intermediate frequency amplifier, while the valve V_6 acts as the second detector, the output of which is coupled through an audio-frequency transformer A_1 to two note amplifiers V_7 and V_8, a switch S_2 cutting out the last note magnifier if desired. When it is not desired to



the components will be dealt with in detail. The input comprises a centre tap frame F tuned by a condenser C_1 connected through a grid condenser and leak G to the grid of the first detector valve V_1, while the other end of the frame is taken to use the receiver as a superheterodyne circuit the anode circuit of the first valve V_1 is connected directly to the audio-frequency transformer A_1, the remaining valves being disconnected from circuit.

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EXPERIMENTAL WIRELESS
& The WIRELESS ENGINEER

VOL. IV. MARCH, 1927. No. 42.

Editorial.

The Future of "Experimental Wireless."

"EXPERIMENTAL WIRELESS" has now been published for something over three years in all, it being just over two years since it was acquired by the present proprietors. During that time we have received many enthusiastic letters from our readers, and have ample evidence that the journal has been of very distinct value in developing and advancing the theory and practice of wireless research.

But the income from the sales of the paper, plus the small revenue we have been able to obtain from advertisers, has not been nearly sufficient to pay the expenses incurred in procuring, printing and issuing suitable editorial matter.

Our publishers have therefore been obliged to consider what steps, if any, can be taken to increase the revenue of the paper, or, alternatively, to reduce production costs to a level more nearly approximating to present, or possible, revenue.

It would, of course, be possible for us by modifying the technical nature of the contents to bring the journal within the requirements of a greatly increased body of readers, in fact it may be said that our readers could be increased in inverse ratio to the technical standard of the journal's contents.

It has been our aim, however, all the time, to cater for a comparatively small but advanced body of readers, and we had hoped that with the assistance of the advertisements of those members of the industry who cater for the requirements of the advanced worker, we should have been able to make the journal pay its way.

We regret to say, however, that we have not received the support that had been anticipated, and it would appear that there are only two courses open to us; either to increase the price of the journal to its public or, seeing that no journal can go on indefinitely as a losing proposition, to abandon its publication.

In the belief that the journal is serving a very useful purpose we have chosen the former alternative, and therefore, commencing with our April number, the price of EXPERIMENTAL WIRELESS will be 2s. 6d. per copy.

It may be that some of our readers will wish to consider carefully whether or not at the higher price their purchase of the journal shall continue. We hope it may, but the decision must rest with them. If the response is sufficient to enable us to carry on the journal without loss, we shall, of course, continue, but failing this, we shall have no option but to discontinue its publication, a course we should very greatly regret.

Should the conditions alter at a later date and it be found possible to make a reduction in the selling price, we shall certainly do so.

But in the meantine our readers must decide if EXPERIMENTAL WIRELESS is worth 2s. 6d. a copy to them, and we must abide by their decision.

Further Measurements on Wireless Wave-Fronts.

By R. L. Smith-Rose, Ph.D., D.Sc., A.M.I.E.E. and R. H. Barfield, M.Sc., A.C.G.I.

1. Introductory.

IN September, 1925, the authors described in this journal* a series of experiments which were based on the determination of the directions of electric and magnetic forces in wireless waves. The main object of these experiments was to ascertain to what extent downcoming waves, reflected or deflected from the upper atmosphere, were present at a receiver on the earth's surface during the occurrence of fading and directional night effects. A necessary part of the investigation was the determination of the conductivity of the ground in the neighbourhood of the receiver, and accordingly a large part of the experimental work consisted in making practical measurements of this quantity in various parts of the country. The results of such experiments showed the conductivity of the earth to be fairly high, and as a result of this it was concluded that it would not be possible to distinguish between downcoming waves and direct, horizontally travelling waves, when working on the long wavelengths for which the apparatus was originally designed. From such theoretical considerations, however, it was shown that the effect of the earth's high conductivity would be less detrimental to the success of the experiments if shorter wavelengths could be employed. The investigation was, therefore, continued with the apparatus modified for more accurate working on shorter wavelengths, while at the same time other methods of attacking the problem have been developed. These later experiments are described in the present article, and, as will be seen, they have proved much more fruitful in results contributing towards the solution of the original problem. Direct evidence has been obtained of the existence of downcoming waves at the earth's surface, and in some cases it has been possible to make fairly accurate measurements of the angle of incidence or elevation at which such waves arrive.

* *E.W. & W.E.*, 1925, Vol. II., p. 737.

2. Description of Apparatus.

In considering the extension of the experiments to shorter waves, it was decided to work on the broadcasting band of wavelengths between 250 and 500 metres, chiefly on account of the availability of transmissions at suitable times within this band. The present section then merely concerns the adaptation of the old apparatus for use on these shorter wavelengths.

The apparatus previously employed consisted of a rotating Hertzian rod receiver for measuring the direction of the electric force in the wave, and of a rotating tilting coil receiver for measuring the direction of the magnetic field.

The adaptation of the Hertzian rod apparatus for short wave working was effected without difficulty. It merely necessitated an improved arrangement of the leads from the rod to the receiving box, together with the substitution of a short-wave amplifier for the long-wave apparatus used hitherto. The apparatus remained substantially as shown in the photograph and diagram forming Figs. 5 and 6 on p. 740 of the previous article.

As regards the apparatus for measuring the direction of the magnetic field, however, it was considered necessary to construct an entirely new short-wave tilting coil. This was chiefly owing to the fact that in the previous paper the conclusion was drawn that the tilt of the magnetic field to the horizontal, which is the quantity to be measured, would not in any circumstances greatly exceed about three degrees on the broadcasting wavelengths. Thus, to make even a rough estimate of the angle of the downcoming wave by this means it would

be necessary to obtain this angular tilt of the coil to an accuracy of about a quarter of a degree.

The principle of the apparatus remained the same but greater attention was given to the details of screening and the accurate levelling and aligning of the axes of rotation, and also to the construction of the graduated scales. For these purposes both the vertical and horizontal axes were made of brass

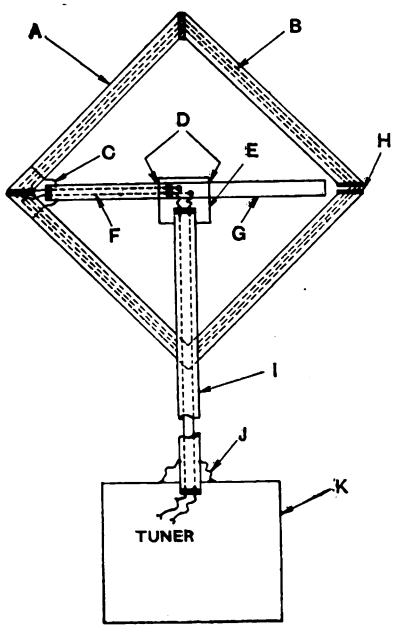

Fig. 1. *Diagram showing the screening arrangement employed on the new tilting coil receiver.*

A *Outer screen of 12 wires (two only shown).*
B *Receiving coil. inside screen.*
C *Screen wires bonded and connected to metal axis.*
D *Bearing.*
E *Screening box protecting flexible connector.*
F *Leading-in wires spaced apart and stretched tight.*
G *Horizontal tubular axis.*
H *Screen loops broken here.*
I *Vertical tubular axis.*
J *Vertical axis. bonded to screening box.*
K *Amplifier and tuning box (metal lined).*

tube of $1\frac{1}{2}$ in. and 1 in. diameter respectively. The leads were taken from the coil through the centre of their tubes down into the screened box which contained the receiving apparatus and into which the lower end of the vertical axis projected (see Fig. 1). In addition to this, the coil itself was surrounded by a screen of open wire loops arranged round the circumference of an imaginary cylinder. Thus, as will be seen from Fig. 1, actually every part of the apparatus was enclosed in a metallic screen protecting it both from direct pick up of signal E.M.F. and from antenna effect. As an extra precaution the hut in which the apparatus was erected was surrounded by a screen of open loops as a further protection against antenna effect (see photo, Fig. 2).

The vertical and horizontal axes of the coil were aligned by means of a plumb line and spirit level permanently attached to the coil, which was supported in a tripod stand with three levelling screws. By this means these axes could be set to an accuracy of 0.1°, while a second level attached to the coil at right angles to the first enabled the horizontal or tilt scale to be adjusted to about the same accuracy. The horizontal axis scale was made specially large so that the angle of tilt could be read to 0.1°.

The leads from the coil were connected to the primary of a tuned coupled circuit, and leads from the secondary were taken to the supersonic heterodyne amplifier employed with this receiver. The whole of this receiver with its associated batteries was enclosed within the screened box, and the telephone leads were brought out through a special screened cable. A sketch-diagram and photograph of the complete tilting frame coil apparatus is shown in Figs. 3A and 3B.

When the set was tested it was found to work very satisfactorily, variations of the tilt angle of 0.1° could be detected and the absolute accuracy of determination of the angle was probably about 0.2°. The apparatus had a conveniently large range of about 200 miles for making accurate measurements on the transmissions from broadcasting stations.

3. Method of making Measurements and Results Obtained.

(A) *Hertzian Rod Apparatus.*

The Hertzian rod apparatus is actuated by rotating the rod until a position is obtained when the signals pass through a minimum intensity or entirely vanish. The rod is then at right angles to the electric lines of force in the wave front. If, then, during this process the horizontal axis about which the rod is rotated is pointing in the direction

of the transmitter, it is clearly the *sideways* tilt of this field which is being measured. If, on the other hand, the horizontal axis is set at right angles to the direction of the transmitter when being rotated, it is the *forwards* tilt which is obtained. These two tilts have been designated respectively as the angles A and B measured from the true vertical, which is the direction the electric force would have in wireless waves travelling over a perfectly conducting earth. The experiments which were carried out with this apparatus consisted in measuring both A and B from instant to instant over a period of several hours, partly by day and partly by night. In the daytime A is invariably zero to within the limits of accuracy of the apparatus, while B has a small positive value, this forward tilt being in effect produced by the imperfect conductivity of the earth.*

Any variation of the angle A from zero is an indication of rotation of the plane of polarisation of the waves, while any variation of the angle B can only be due to the action of waves arriving at a definite angle of inclination to the earth's surface.

The results obtained from these measurements were plotted in the form of curves, and an example of these curves is shown in Fig. 4. It is at once apparent that though A and B remain steady during the day-time they are subject to marked variations in the neighbourhood of sunset and during the hours of darkness.

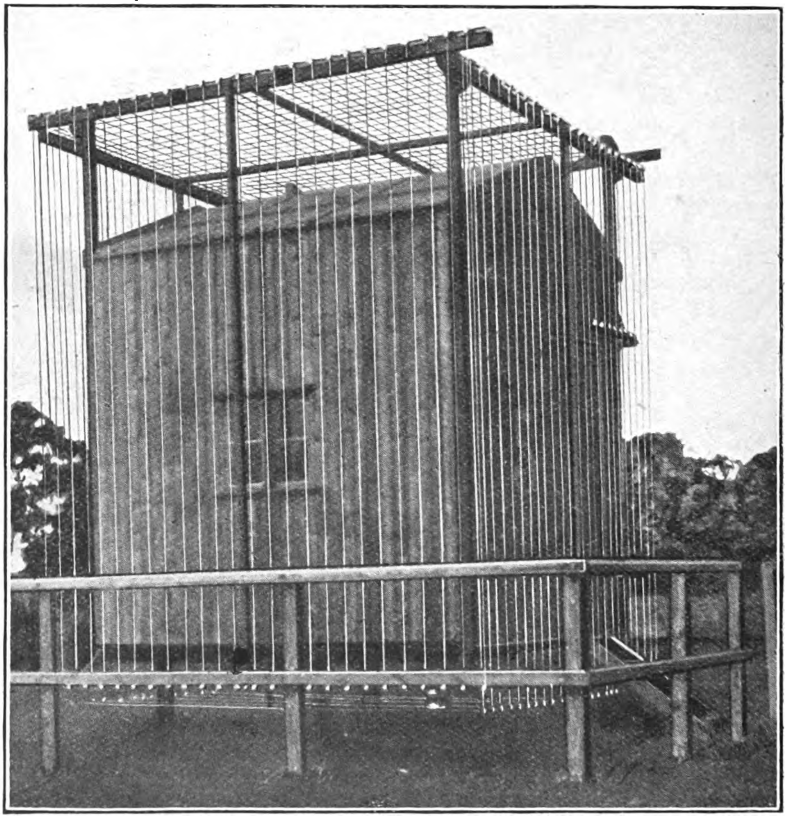

Fig. 2. *Photograph of hut containing the tilting coil apparatus, showing the arrangement of the surrounding wire screen for the reduction of antenna effect on the frame coil receiver.*

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* See previous article, *E.W. & W.E.*, 1925, Vol. II., p. 737.

We therefore have without any further analysis whatever very strong evidence (*a*) that the plane of polarisation of the waves is varying, and (*b*) of the existence of down-

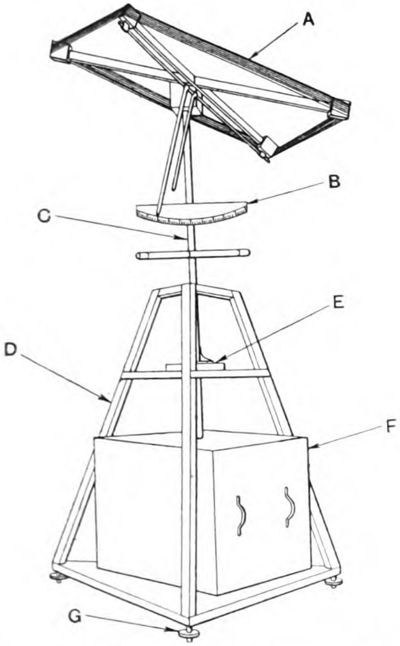

Fig. 3A. *Sketch diagram of the tilting coil receiver.*

A *Tilting frame coil.*
B *Scale for horizontal tilts or elevation.*
C *Vertical brass axis containing leads from coil to receiver.*
D *Tripod stand supporting frame coil.*
E *Scale for bearings or azimuth.*
F *Screened box containing receiving apparatus.*
G *Levelling screws for stand.*

coming waves. With this important conclusion concerning questions, which have so long remained unanswered, we will leave the Hertzian rod apparatus for the time being and turn to a consideration of the experiments carried out with the tilting coil.

(B) *Tilting Coil Apparatus.*

The direction of three of the components of the magnetic field of the waves could be observed by means of this apparatus: first, the direction of horizontal component designated by the angle "*C*" corresponding to the error in bearing of the transmitting station; secondly, that of the component in the vertical plane at right angles to the vertical plane of propagation designated by the angle "*D*"; and lastly the direction of the component in the plane of propagation designated by the angle "*F*." The angles "*D*" and "*F*" are measured from the horizontal, which is the normal direction of the magnetic field in wireless waves at the surface of a perfectly conducting earth. In all cases the measurements were made by determining the position of the coil when the received signal intensity passed through a minimum or zero. The angle "*C*" is measured by fixing the coil in a vertical plane and rotating it about its vertical axis. The angle "*D*" is measured by rotating the coil about its horizontal axis with that axis pointing directly away from the transmitter, while the angle "*F*" is measured by rotating the coil about its horizontal axis with that axis fixed in a direction at right angles to that of the transmitter.

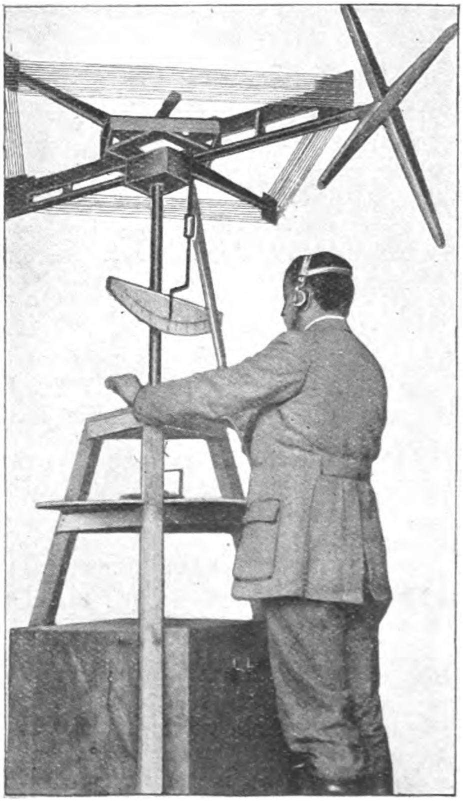

Fig. 3B. *Photograph of the tilting frame coil receiver in operation.*

Observations of these three angles were made during many periods of several hours' duration, usually at the same time that experiments with the Hertzian rod apparatus were being carried out. Some typical results are shown in Figs. 5 and 6 where they are recorded in the form of curves.

It will be seen that at night variations in all of three of the angles were observed, whereas it will be remembered that in the case of the longer waves only the angle C was found to alter.*

measured at all is almost conclusive proof of the arrival of a horizontally polarised downcoming wave. Thus the measurements of the direction of the magnetic field of the waves by means of the tilting coil receiver confirm the conclusions obtained from the experiments with the Hertzian rod apparatus. Further, it was found that whenever large variations of the apparent bearing were observed, the other angles A, B, D, F were also varying. This constitutes a very substantial proof that what has hitherto been

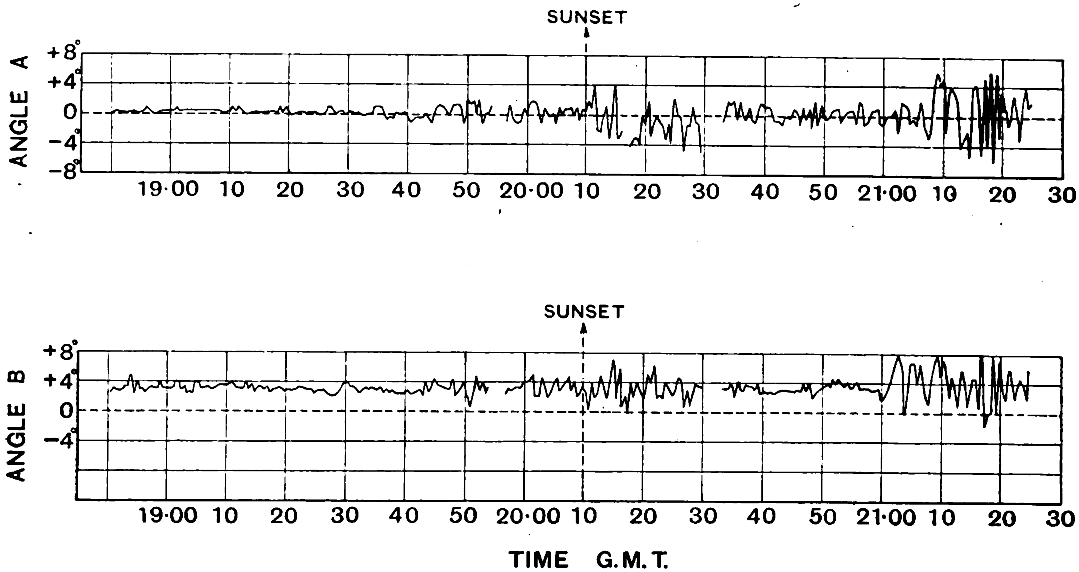

Fig. 4. *Observation of sideways and forwards tilt of electric field (angles* A *and* B) *made at Slough on transmissions from Bournemouth, 4th June,* 1925. *Wavelength* = 386 *metres.*

It is thus immediately evident from these results that variations in apparent bearings obtained on a frame-coil direction-finder are accompanied by variations in the angle of inclination of the magnetic field in the waves to the horizontal. The fact that the angle D can have a value other than zero indicates the arrival of waves with their plane of polarisation rotated from the normal position. As regards the angle F, a little consideration makes it clear that since under normal conditions no signal at all can be received with the coil in the position in which this angle is observed, the fact that it can be

vaguely referred to as "night effect" in wireless direction-finding is due to the presence of downcoming horizontally polarised waves at the receiver. The original theory and experiments of T. L. Eckersley* in this direction are thus adequately confirmed, and the general results are in agreement with the recent work of Appleton and Barnett† on the cause of fading of wireless signals.

* See previous article.

* T. L. Eckersley, *Radio Review*, 1921, Vol. 2, pp. 60 to 65, and 231 to 248.

† E. V. Appleton and M. A. F. Barnett, *Nature*, 1925, Vol. 115, p. 333, and *Proc. Roy. Soc.*, 1925, Vol. 109, p. 621.

4. Calculation of Angle of Incidence of Downcoming Waves.

We have now shown how properly constructed apparatus for measuring the inclination of the electric and magnetic forces in wireless waves may at once provide indisputable evidence of the existence of waves deflected from the upper atmosphere. It is now proposed to go further and demonstrate how the data so obtained may be made use of for the calculation of the actual angle of incidence and relative intensity of these downcoming waves.*

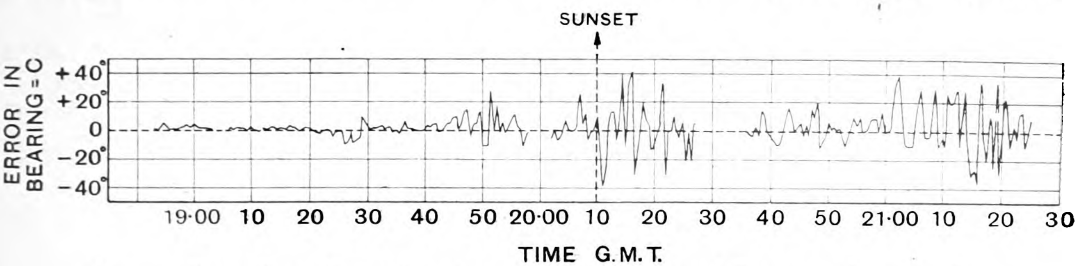

Fig. 5. *Observations of error in apparent bearing (angle* C*) of Bournemouth at Slough through a sunset period, 4th June, 1925. Wavelength = 386 metres.*

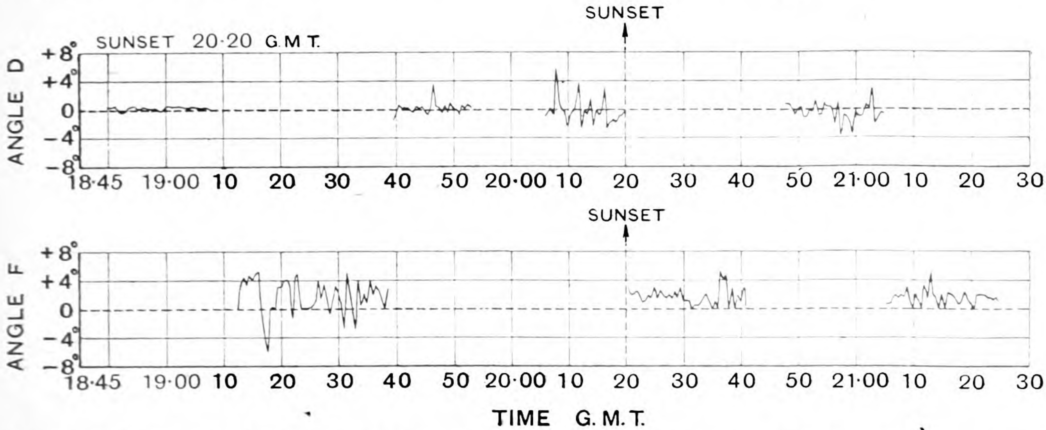

Fig. 6. *Observations of angles* D *and* F *on Bournemouth, 18th June, 1925. Wavelength = 386 metres.*

(A) *With Hertzian Rod Apparatus.*

Fig. 7 depicts a single wave of field strength E arriving at a receiver at O with an angle of incidence θ. The incident wave gives rise to a reflected wave with angle of reflection θ and intensity $\rho_v E$ where ρ_v is called the reflective power of the earth. The current induced in the Hertzian rod apparatus or in any aerial is clearly due to the resultant field of these two waves.

Let this resultant field be split up into a horizontal component X and a vertical component Z. Then if the resultant field is linear the angle of tilt B measured by the Hertzian rod apparatus is clearly given by

$$\tan B = \frac{X}{Z} \quad \ldots \quad \ldots \quad (1)$$

Now it can be shown from the elementary theory of plane electromagnetic waves that

$$\frac{X}{Z} = \frac{1}{\sqrt{K'}\sin\theta} \quad \ldots \quad \ldots \quad (2)$$

where K' is a constant depending chiefly on the conductivity of the ground and the

* A fuller discussion of the theoretical treatment used in this and the succeeding sections will be found in a paper recently published by the present authors.—*Proc. Roy. Soc.*, 1926, Vol. 110, p. 580.

wavelength; so that we now have a formula for obtaining θ, viz. :—

$$\sin\theta = \frac{1}{\sqrt{K'}} \cot B \quad \ldots \quad (3)$$

We have not, however, yet arrived at the practical case as experienced during the investigation, for the above reasoning assumes the existence of a *single* arriving wave only at the receiver. Thus if we use the above formulæ we shall be determining the resultant angle of incidence of all the waves arriving, including that of the direct or surface travelling wave for which we know $\theta=90°$ (approx.).

In order to distinguish between the direct and downcoming waves at any instant we must know their relative magnitudes and also the phase relation between them.

For this purpose apparatus was constructed which enabled the relative signal strength as obtained on a vertical antenna to be measured. It consisted of a simple coupled circuit receiver connected to a three-stage untuned transformer-coupled H.F. amplifier and valve detector. A sensitive mirror galvanometer recorded the change in anode current of the detector valve, the normal anode current being balanced out through the galvanometer by means of a potentiometer. With this apparatus it was possible to detect changes in the anode current corresponding to a variation of 1 or 2 per cent. in the signal strength. During its operation the apparatus was calibrated from time to time by means of a specially constructed screened oscillator. Observations were made on this signal strength apparatus simultaneously with the observations on the tilting coil and Hertzian rod apparatus.

Since a vertical antenna was employed with this signal strength measuring instrument, the quantity measured by it is the total value of the vertical component of the electric field, a quantity which we have already designated as Z.

Let us divide the resultant vertical electric field Z up into two compounds, Z_0 due to the direct wave and Z_1 the contribution of the downcoming wave or waves.

The horizontal electric field X may be divided into two similar parts and if θ is taken to be the mean angle of incidence of the downcoming waves, its value will be given by the expression :—

$$\frac{X_1}{Z_1} = \frac{1}{\sqrt{K'}} \sin\theta \quad \ldots \quad (4)$$

But assuming that the direct wave alone is present in the daytime and does not change in intensity during night effect we have :—

$$\left.\begin{aligned} Z_1 &= Z - Z_0 \\ X_1 &= X - X_0 \end{aligned}\right\} \ldots \quad \ldots \quad (5)$$

Also in the daytime

$$\frac{X_0}{Z_0} = \tan B_0 \quad \ldots \quad \ldots \quad (6)$$

where B_0 is the normal forward tilt of the electric force arising from the finite conductivity of the earth. Hence from equations (3), (4), (5) and (6) we get the expression for the angle of incidence of the downcoming wave as :—

$$\sin\theta = \frac{Z - Z_0}{\sqrt{K'}(Z \tan B - Z_0 \tan B_0)} \quad (7)$$

in which all the quantities are constant or measurable by means of the Hertzian rod or signal strength apparatus.

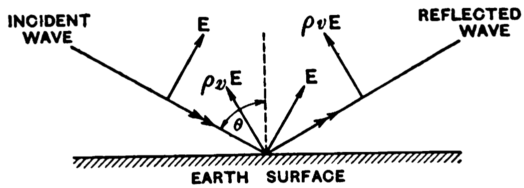

Fig. 7. *Showing the directions of the electric force in incident and reflected waves at the surface of the earth.*

A difficulty that was found to arise in practice was that during the occurrence of night effect the quantities Z and B varied so rapidly that in order to be able to plot a continuous curve of their instantaneous values it was found necessary to take readings at the rate of about one per five seconds. Although this was quite possible with the signal strength apparatus it was not so with the Hertzian rod apparatus owing to the unwieldy nature of its moving parts. Consequently it could not be guaranteed that the values of Z obtained corresponded to those of B at any given instant—a condition which must be fulfilled before equation (7) can be applied. It was therefore not possible to

calculate the angle of incidence but by noting the maximum intensity of the downcoming wave over a short period on either side of instant at which B was measured, it was possible to obtain the ***maximum*** value of θ at that instant, a result which was naturally of considerable interest on many occasions.

(B) *With Tilting Coil Apparatus.*

Owing to the fact that there is no horizontally polarised direct wave the angle of incidence of the wave can be obtained directly from the measurements made on the tilting coil apparatus of the angle F by means of the relation

$$\sin \theta = \sqrt{K'} \tan F \quad \ldots \quad (8)$$

It is, however, necessary to make sure that at the instant at which F is measured the intensity of the downcoming wave is at least of the same order as that of the direct wave, for without this precaution instrumental errors are liable to arise of sufficient magnitude to vitiate the conclusions drawn from the calculation.

Particular examples of the value of the angle of incidence of the downcoming wave as obtained by this method are given in Table I. for observations made at Slough on the Bournemouth B.B.C. station.

TABLE I.

CALCULATION OF θ FROM ANGLE F.

OBSERVATIONS ON BOURNEMOUTH BROADCASTING STATION.

Date.	Time G.M.T.	F degrees.	θ degrees.	$\frac{E_1}{E_0}$
18.6.25	2107½	1.6	28	1.2
,,	2122½	2.0	34	0.6
,,	2124	1.2	19	0.5
25.6.25	2045	2.0	34	0.3
,,	2112½	1.0	16	>1.1
,,	2113	1.0	16	>1.1
,,	2113½	2.0	34	>1.2
,,	2114	2.0	34	>1.2

The two most interesting conclusions derived from this table are (1) that the angle of incidence can attain such a small value as 16° (*i.e.*, showing waves arriving at a very steep inclination) and (2) that θ can change rapidly within a few seconds, a fact which it scarcely seems possible to explain in any other way than by supposing that there are at times at least two downcoming waves at widely different angles of incidence and both varying rapidly in intensity and phase.

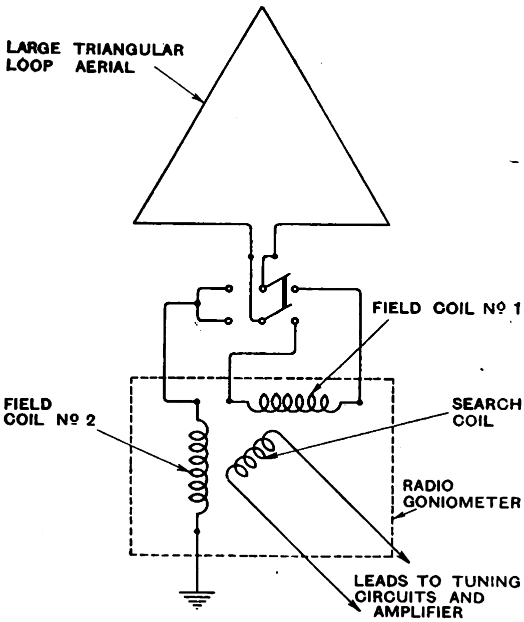

Fig. 8. *Circuit arrangement showing the loop-aerial method of comparing the intensity of the horizontal magnetic force and the vertical electric force in wireless waves.*

5. Improved Method of Obtaining Angle of Incidence of Vertically Polarised Waves.

The failure of the Hertzian rod apparatus for the actual measurement of θ owing to the rapidity of the night variations was fortunately not a great set back, as another and far more accurate method of obtaining the angle of incidence of the vertically polarised wave had been simultaneously developed.

A large receiving loop, formed of a triangle of height about 50 ft. and base about 60 ft., was erected in a vertical plane aligned accurately on the transmitting station under observation. This was connected to one or other of the field coils of a radiogoniometer at will by means of a change over switch, but arranged so that the loop was in series with the one field coil in one position of the switch and in the other position short

circuited and connected to earth through the other field coils. The alternate circuits and the complete circuit diagram are shown in Fig. 8.

Considering now that the search coil of the goniometer is fixed in a given position the signal strength in position (1) is determined by the total magnetic field of all the vertically polarised waves that may be arriving. We will designate this magnetic field as β. In position (2) the signal strength is determined by the intensity of the total vertical electric field which we have already called Z.

To operate the apparatus the switch is rapidly alternated between the two positions while at the same time the search coil is rotated until a balance (*i.e.*, equal strength) is obtained. The construction of the goniometer is such that the tangent of the search coil angle is proportional to the current ratio in the two field coils and therefore to the ratio β/Z.

An elementary inspection of the phenomenon of the reflection of electromagnetic waves at a plane surface will bring to light the fact that

$$\beta/Z = \frac{1}{\sin\theta} \quad \ldots \quad \ldots \quad (9)$$

whatever may be the value of the conductivity of the surface.

By remembering that for a direct wave $\beta = Z$ (*i.e.*, electric field=magnetic field) we are able to get the absolute value of β/Z from the relative measurement which is all the above method affords.

Since we wish to distinguish between the downcoming wave and the direct wave we cannot use the simple formula (9) unless we are sure there is no direct wave present. In the experiments we are now describing this was not the case. Therefore, as with the Hertzian rod apparatus, it was necessary to obtain the relative intensity of the downcoming wave at the instant a determination of β/Z was made. This was done as before by simultaneously measuring Z.

The complete formula for obtaining θ has then to be modified in much the same way as was adopted above by introducing the component values of Z, Z_0 and Z_1. Thus from (9)

$$\sin\theta = \frac{Z_1}{\beta_1}$$

$$= \frac{Z - Z_0}{\beta \quad \beta_0}$$

so that

$$\sin\theta = \frac{Z - Z_0}{\frac{\beta}{Z} \times Z - Z_0} \quad \ldots \quad (10)$$

since $Z_0 = \beta_0$, where now all the quantities in (10) are directly measurable.

Since the apparatus could be operated sufficiently rapidly to follow continuously the changes in the value of β/Z, formula (10) could actually be applied to calculate instantaneous values of θ. This was done for many hundreds of instants at which observations had been made and thus the angle of incidence was obtained on a number of occasions. Table II. shows some typical results of measurements.

TABLE II.

CALCULATION OF ANGLE OF INCIDENCE AND RELATIVE INTENSITY OF DOWNCOMING WAVES RECEIVED FROM BOURNEMOUTH BROADCASTING STATION.

Date.	Time G.M.T.	Z.	β/Z.	θ degrees.	$\frac{E_1}{E_0}$
18.6.25	2030.00	17.0	1.6	21	0.7
,,	2032.50	15.2	1.3	27	0.4
,,	2034.40	16.5	1.4	25	0.6
,,	2102.10	16.5	1.6	21	0.7
,,	2104.05	20.0	1.9	19	1.2
,,	2104.25	19.6	2.1	17	1.4
25.6.25	2030.00	14.8	1.4	21	0.4
,,	2100.00	14.2	1.4	19	0.4
,,	2103.40	19.7	1.7	23	1.1

They are very interesting in showing that as with the horizontally polarised waves very small values of θ are possible and that these values may vary between fairly wide limits.

6. Calculation of Intensity of Downcoming Waves.

Having obtained the angle of incidence of the downcoming waves at a given instant, it is not a difficult matter to obtain the relative intensity of the downcoming waves.

In the case of the vertically polarised waves we calculate the intensity of the total horizontal magnetic component β from the measured values of Z and β/Z at a given instant and subtract from this the day-time value of the component, $B_0(=Z_0)$. This gives β_1 the horizontal magnetic field, resulting from the combination of the incident and reflected waves. The amplitude of the incident wave is approximately half the value since there is nearly perfect

reflection at the earth's surface, with the wavelengths under consideration.

The intensity of the horizontally polarised downcoming wave is obtained in much the same way. For this purpose, however, it is necessary to know the value of the horizontal component of the magnetic field of this wave, *i.e.*, that component which is responsible for the signals induced in a loop receiver aligned at right angles to the transmitting stations. This quantity (α) was measured indirectly by comparing the signal obtained by such a loop with those from a vertical aerial by exactly the same method employed in obtaining the quantity β/Z. It can be shown that if E_1 is the amplitude of the downcoming horizontally polarised wave

$$E_1 = \frac{\alpha}{2 \cos \theta} \text{ (approx.)} \quad \ldots \quad \ldots \text{ (11)}$$

The values of the relative intensities of the downcoming waves as obtained in this way are given in the Tables I. and II. for each occasion that the angle of incidence was measured.

In the example given the intensity ranges from 0.3 to over 1.2 times that of the direct ray and this is typical of the values obtained throughout the experiments made on the transmissions from the Bournemouth Station.

7. General Conclusions.

It will be convenient to conclude this article by summarising the most important conclusions to be derived from these experiments. In the first place, no less than three independent methods have definitely shown the existence of downward reflected waves during the occurrence of the phenomena usually referred to as night effect in direction-finding or as fading in signal intensity measurements. Secondly, two of these lines of attack have clearly shown that the downcoming waves in nearly every case contain horizontally polarised components and thus make it highly probable that the waves are circularly or elliptically polarised. Thirdly, all three methods indicate that in the case of the experiments made on the transmissions from Bournemouth more than one downcoming wave is often present.

Further, the angle of incidence of the waves has been measured by two of the methods and its maximum value on definite occasion obtained by the third. The results in the particular case of the station first investigated (Bournemouth) show angles of incidence varying from 16° to 34°, while the angle of incidence may change from one limit to the other, or have any intermediate value in a very short space of time.

The most convenient way of explaining the plurality of angles of incidence is that multiple reflection from the upper layer is taking place. The largest angle observed during a given period will then correspond to a single reflection, and assuming the ordinary laws of reflection to hold, this makes the height of the upper ionised layer about 90 kilometres.

To account for the smaller angles of incidence observed, it may be supposed that the waves are reflected alternately at the upper ionised layer and the earth's surface. This is quite reasonable since with a value of the earth's conductivity as obtained in the author's previous measurements, the reflective power of the earth is of the order of 0.9 for small angles of incidence. For waves which had suffered two successive reflections from the upper layer at a height of 90 kilometres, as in the above case, the angle of incidence would be about 19°, which is in the neighbourhood of the lower limit recorded above.

In conclusion, the results here described are only to be regarded as of a preliminary nature. The investigation is being continued and it is hoped to publish a further report in the near future in which the outcome of its application to a number of other transmitting stations at other distances and on other wavelengths will be duly set forth.

Telephone Transmitter Modulation Measured at the Receiving Station.

By Balth. van der Pol, D.Sc., and K. Posthumus, E.E.

(*N. V. Philips' Gloeilampenfabrieken, Eindhoven, Holland*).

IN connection with a paper by Mr. L. B. Turner under the same title and published in *E.W. & W.E.*, January, 1927, it may be of interest to give a short account of a somewhat different method of modulation measurement which has been in use for some time in this laboratory. The method was used some time ago in an official test of the modulation of the Dutch Hilversum Station, the measurements being made in Eindhoven.

Our method, in which the modulation of a transmitter is measured at a receiving station, has the advantage of—

(*a*) requiring a very limited number of instruments, and

(*b*) of enabling one to know exactly what quantity is being measured.

Referring to Fig. 1, let L_1C_1 be a circuit tuned to the incoming frequency. This circuit is placed at the end of an H.F. amplifier delivering to the circuit a high frequency amplitude of about 10 volts or more. The greater this voltage the more accurate the results will be.

This H.F. alternating voltage is rectified by the diode D_1 (triode with grid connected to anode) with the aid of the capacity C_2 (500 $\mu\mu F$) and the resistance r (300,000 ohms). The values of C_2 and r are chosen in such a way (as is usual with grid rectification) that C_2 can be regarded as a short circuit for the high frequency current and as an open circuit for the low frequency current.

The potential across C_2 has therefore the form of Fig. 2, where n is the modulation frequency.

Further, with the aid of the diode D_2, the microammeter μA, and the battery B, together with the potential divider P, the crest value A and the minimum value B of Fig. 2 can be measured. In order to measure the voltage A (Fig. 2) it is only necessary to put the switch S on the A position, and to vary P till the current through the microammeter just vanishes. The reading of the direct current voltmeter $V_{D.C.}$ then gives one the voltage A of Fig. 2. When thereupon the switch S is moved to the position B and

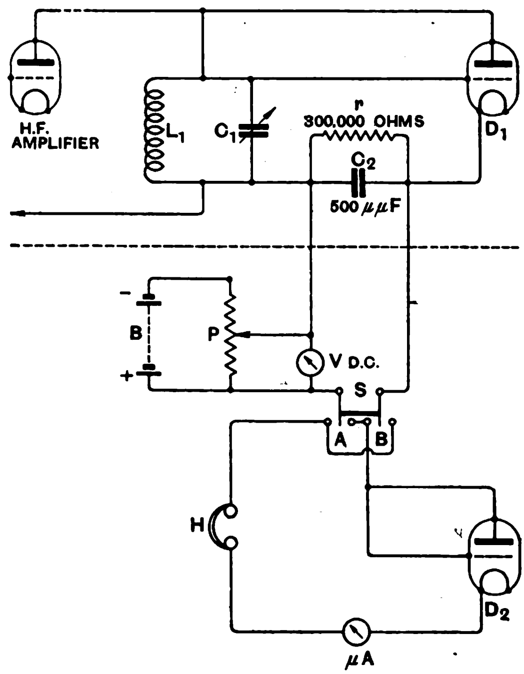

Fig. 1. *Circuit arrangement.*

the measurement is done in exactly the same way, the reading of $V_{D.C.}$ will give the voltage B of Fig. 2. When the microphone of the transmitter is quiescent, the two readings of the voltmeter $V_{D.C.}$ ought to be the same for both positions A and B of the switch S.

In carrying out the experiment one can listen in the telephones H. It will be noticed that these telephones are not absolutely silent at the moment when, by the

aid of the potential divider P, the micro-ammeter is brought to zero. The reason is obviously that the diode passes some audio-frequency current through its capacity. However, as soon as, by a small change of the setting of P, the microammeter begins to show a current, a peculiar cracking noise will be heard in the telephones, resulting from the peaks of the modulation being passed by the diode D_2. This moment, when the microammeter begins to pass the slightest current, can plainly be recognised by the peculiar sound in the telephones, so that in practice the microammeter μA can be dispensed with altogether.

The maximum and minimum value A and B being thus read from the voltmeter $V_{D.C.}$ the modulation ratio M can be determined from the formula

$$M = \frac{A - B}{A + B}$$

Incidentally, our method enables one to verify whether or not the carrier wave of a transmitter is changed in *mean* amplitude by the modulation. For when, as it ought to be, there is no change in the mean amplitude, the readings A and B during modulation will be such that they are related to the readings A_0 and B_0 when unmodulated by the equation

$$A_0 = B_0 = \tfrac{1}{2}(A + B).$$

When a high degree of accuracy is required one can determine the values of A and B within about 2 per cent. when the following precautions are taken :—

1. The modulation of the transmitter must be constant during *one* set of measurements (preferably the modulation must be a continuous constant note).

2. The H.F. amplitude across the L_1C_1 circuit must be of the order of 20 volts.

3. Small contact potential differences of the diodes D_1 and D_2 must be compensated by the insertion of a small P.D. (of the order of 1 volt or less, depending on the diodes used) in series with the anodes of these valves.

In conclusion, and in order to give some idea of the working of this circuit, we insert a set of measurements taken on the Hilversum Station during some special tests :—

1. Unmodulated
   ($I_{ant} = 14.5$ amps). $A = 17.75$V
   $B = 17.75$V, $M = 0\%$, $\dfrac{A+B}{2} = 17.75$
2. Tuning note
   ($I_{ant} = 14.7$ amps). $A = 25.75$V
   $B = 10.75$V, $M = 41\%$, $\dfrac{A+B}{2} = 18.25$

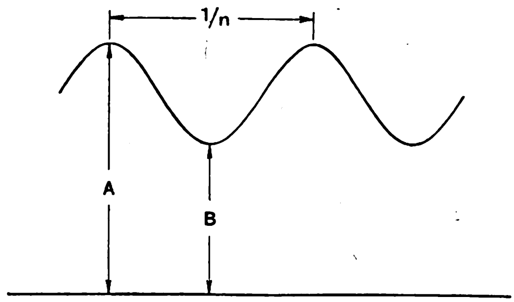

Fig. 2.

3. Organ
   ($I_{ant} = 14.5$ amps). $A = 22.4$V
   $B = 12.9$V, $M = 27\%$, $\dfrac{A+B}{2} = 17.65.$
4. Tuning note (strong modulation)
   ($I_{ant} = 15.6$ amps). $A = 34.75$V
   $B = 9.25$V, $M = 58\%$, $\dfrac{A+B}{2} = 22.$
5. Speech
   $A = 20.75 - 23.75$, $B = 16.65 - 14.25$
   $M = 11\% - 25\%$, $\dfrac{A+B}{2} = 18.7 - 19.$

Spanish High-Power Station.

THE station at Prado del Rey about five miles west of Madrid and about 2,200 ft. above sea level has been erected by the Telefunken Company. The building was commenced in 1922. The aerial is supported on four masts 700 ft. high, square

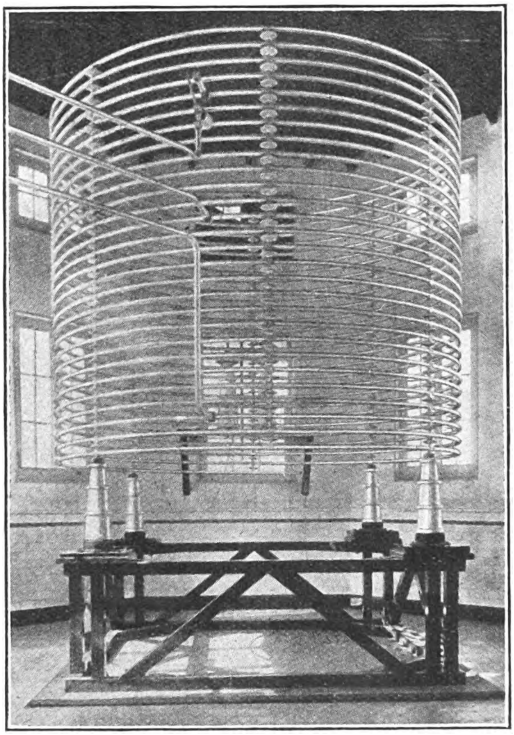

Fig. 1. *Copper tube aerial tuning coil.*

lattice structures of weldless drawn steel tubes, erected on the Ljungberg system. The aerial is of aluminium strand varying from 14.5 to 23 mm. diameter; the capacity is 18,000 $\mu\mu$F, the natural wavelength 5,300 metres, and the effective height 165 metres. Power can be drawn from a hydro-electric system or can be generated at the station by a 400 h.p. Diesel engine coupled to a 3-phase generator. The high frequency current is generated by an alternator coupled to a 3-phase induction motor; the generated frequency is 7,500, but this can be multiplied by 3, 4 or 5 by means of suitable transformers with saturated iron cores. There are thus three working wavelengths, viz., 13,870, 10,560 and 8,340 metres, of which the longest is regarded as the main. The installation is designed to deliver 150 kilowatts. Fig. 1 shows the aerial tuning coil of 30 mm. copper tube with its three tappings corresponding to the three wavelengths.

The receiving station is at Morata, 16 miles S.E. of Madrid and about 20 miles from Prado del Rey.

Fig. 2 shows the picturesque receiving building. The large tower contains the large revolving frame of 16 square metres area, the smaller tower one of 3 square metres area. The upper parts of these towers are particularly free from iron, whereas the ground floor room containing the instruments has a four-fold sheet iron lining.

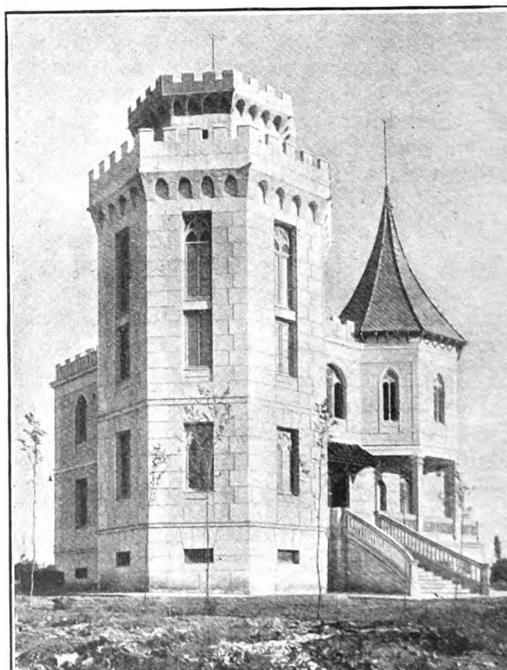

Fig. 2. *The unique building of the receiving station.*

Both transmission and reception are carried out at an office in Madrid from which overhead wires run to Prado del Rey and Morata.

G.W.O.H.

The Horizontal Hertzian Aerial for Transmission.

By Marcus G. Scroggie, B.Sc.

THE attention which is being directed to the use of short radio waves for long-distance communication has been responsible for considerable investigation into the matter of the most effective radiating system. For all waves longer than about 100 metres some form of inverted L or T aerial is almost always used, in conjunction with a buried earth connection, an earth screen or counterpoise, or a combination of these ; the dimensions being roughly proportional to the wavelength to be radiated.

This type of aerial in normal circumstances radiates waves in which the electric field is vertically polarised, and the effect of the "flat top" has until comparatively recently been generally regarded as useful only in so far as it increases the effective height by increasing the capacity and so permitting more current in the vertical part of the aerial. The radiation from a horizontal wire has no effect on a distant receiver using a purely vertical aerial, provided its polarisation is not altered between the stations. Recent work, more particularly on short waves, has given rise to a reconsideration of the most effective form of aerial.

In an aerial system the arrangement of conductors must be chosen so that the inductance and capacity are correct for the wavelength to be radiated, but that condition fulfilled, the effectiveness of the aerial is mainly controlled by the resistance, which in its broad sense is of two principal kinds—the radiation resistance and the rest. The former should be as great as possible compared with the latter. Radiation resistance only begins to count when the physical dimensions of the circuit are of the same order as the wavelength, so it is desirable to have it opened out as much as possible. This condition is obviously best fulfilled by two straight rods or wires pointing away from one another, and this also happens to be the simplest arrangement, and was used by the first man ever to make a practical study of these radiations—Heinrich Hertz. It is true he complicated this simple system slightly by adding metal plates at the end of the rods to increase the capacity, but the general scheme of things was the same. (Fig. 1.)

The source of oscillations is introduced in the centre, and the plates are charged alternately in each direction. As a simple rod aerial, apart from loading, oscillates at a wavelength only double its own length, it would hardly be practicable in the case of, say, a 15,000 metre commercial station, to have a vertical rod $4\frac{1}{2}$ miles long with the transmitting station half-way up, though doubtless this would be a most admirable scheme from the point of view of efficiency. But for short waves, where the length of the aerial is reasonable, it is quite feasible to make use of it. Thus for 45 metres, which is of the order of wavelength most favoured for long-distance low-power work, the aerial is about 70 ft. long, which is quite suitable in ordinary situations.

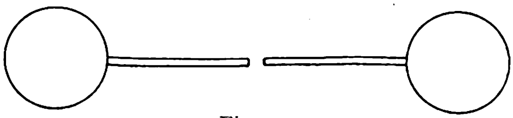

Fig. 1.

The aerial can be placed at any angle, but it is most convenient to have it horizontal. It has been stated already that horizontally polarised waves, *if they are unaffected en route*, cannot be received on a vertical aerial. But in this world of imperfections they do not proceed in this unmolested manner, but on arrival are found to be quite badly distorted, and instead of being all in their original plane they will have a component at right angles. In general these components will not be equal (circularly polarised) but will be more in one direction than others (elliptically polarised). In the case of short waves, which are more liable

to this form of alteration, the major axis of the ellipse may be at right angles to the original plane of polarisation. Smith-Rose and Barfield* have carried out a careful series of experiments, mainly with fairly long waves, which only exhibit this effect to a comparatively limited extent. Other investigators who have made measurements on this subject are referred to in their article.

In the case of short waves, the unexpectedly long ranges obtained with them are generally explained by supposing them to be reflected from the conducting Heaviside layer some 70 or 80 kilometres above the earth's surface, and thus avoiding the very large absorption on the ground-level which would otherwise render them inappreciable at a few miles distance. Their polarisation on arrival may therefore be greatly different from the original. In passing, it may be noted as an analogy that light waves reflected from clouds overhead are slightly polarised.

Some interesting measurements on short waves made by Pickard are described in *Q.S.T.*† The ratio of horizontal to vertical strength of originally vertical waves was measured for varying wavelengths, distances and times of the day. It was found that horizontal effects were greater at night, with the shorter waves and at great distances. With waves of the order of 80 metres the ratio of horizontal to vertical was greater than 1 at distances over about 25 miles, and amounted to 2.4 in cases. On the 40 metre band, horizontal reception formed as much as five-sixths of the whole.

Conversely, if one starts with horizontal waves, one would expect to receive them quite well on a vertical aerial in the above circumstances.

This matter has been gone into by the General Electric Company of America, who have found it advantageous to work with horizontally polarised short waves. In this case it will be clear from the preceding considerations that a receiver near the transmitter will receive very little, best reception being obtained at great distances. This is of course a most desirable feature, particularly for duplex work.

Experiments in short wave transmission, using the simple Hertz aerial, have been carried out in America at the KDKA station, but these have, as far as the writer is aware, been confined to vertical aerials. So far as is known, no information is available as to reception in this country of this station on a horizontal aerial receiver. It must be pointed out that even if the lead-in is screened, an inverted L aerial does not give horizontal reception. It is necessary for the receiver to be inserted at the midpoint, and in addition to be carefully screened.

Granted that a horizontal Hertz, supported as far away as possible from everything else, is a desirable form of aerial for short waves, providing as it does the maximum ratio of radiation resistance to loss resistance, a difficulty is at once apparent. In order to excite the aerial it is necessary to introduce some oscillating source at its midpoint. Although it is not entirely out of the question, it is not in general convenient to have the transmitter high up in the air at the centre of the aerial. It is quite usual to have some form of current-indicating instrument located at that point, either an ammeter read through a telescope (daylight), or a lamp (night), but a centrally situated transmitter is only practicable for extremely short waves, as in beam experiments, etc.

It might seem that any form of line for conveying the radio-frequency energy to the aerial would upset its characteristics, but fortunately it is possible to convey energy to the centre of the aerial from the transmitter quite a distance away, and yet to produce sensibly the same results as if the transmitter were centrally located. This is sometimes done by means of a wire connected from a tapping on the transmitting inductance, or a coil coupled thereto, to a point on the aerial a little to one side from the centre. This method is now fairly well known, but the method employing the principle of standing waves on parallel wires is less familiar, and possesses some features of interest.

As far back as 1890 E. Lecher described his arrangement of two parallel wires which could be used for the direct measurement of the wavelength of electrical oscillations. The whole matter is very fully gone into in Scientific Paper No. 491 of the *Bureau of Standards*, and those who wish detailed

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* "Some Measurements on Wireless Wave-Fronts." R. L. Smith-Rose and R. H. Barfield. *E.W. & W.E.*, Vol. II., pp. 737-749.

† "Horizontal Reception." R. S. Kruse. *Q.S.T.*, February, 1926, pp. 9-17.

information are recommended to consult this. Briefly, it may be explained that if oscillatory voltages are induced into one end of a pair of parallel wires, standing waves are set up on them; that is to say, for any given wavelength there are certain fixed points on the wires where there is a high potential between them, and these points occur at half a wavelength apart.

These may be detected by some potential indicator, such as a neon tube which will glow at these points. For actual measurements the *Bureau of Standards* shows that it is better to short-circuit the lines with a low-resistance thermal ammeter and to measure the distance between consecutive points

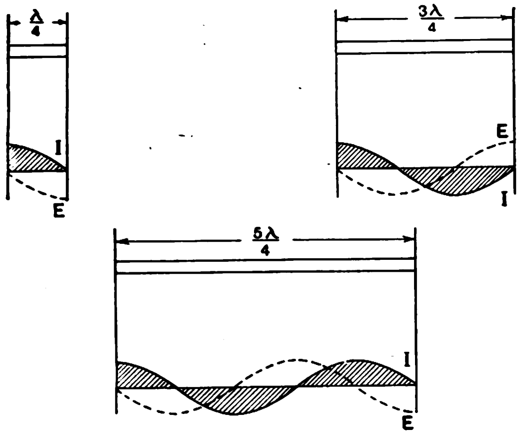

Fig. 2.

where maximum readings are obtained, which is half the wavelength impressed on the line.

The distribution of current and potential is different according as the line is open or closed. This can best be shown by diagrams. The principles are that the current and potential are 90° out of phase (when one is zero the other is maximum), that with an open line potential is a maximum at the free end, and with a closed line current is a maximum at this end. Further, in order that energy should be transferred into the line the current should be a maximum at the commencement.

Supposing the line to be open at the end, the distribution of current and voltage is shown in Fig. 2 for various lengths. In each of these cases the current is a minimum at the input, and the standing waves will not be detected. If the line lengths are as in Fig. 3 this state of things will be reversed. If the length of line is fixed and the wavelength varied each of these conditions can be noted in turn by connecting a neon tube

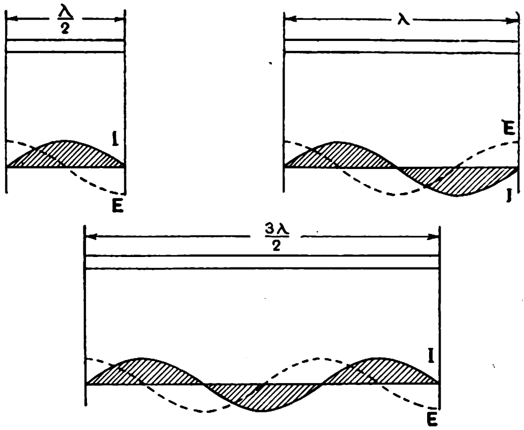

Fig. 3.

across the free end of the wires; this will show the maximum of potential (E) by the brightness of its glow. The same glow will of course be obtained at all points where there is a maximum.

With a line closed at its free end by a short-circuiting bar or low-resistance ammeter, the distributions are reversed (Figs. 4 and 5).

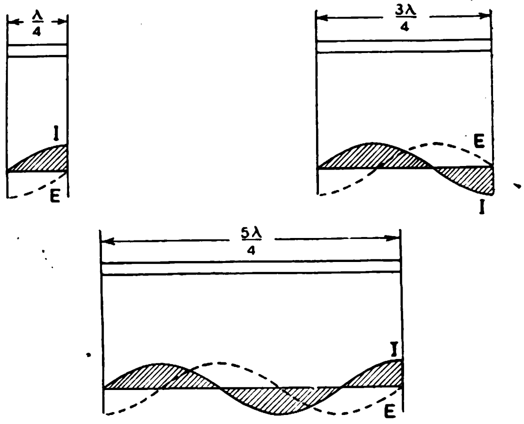

Fig. 4.

The conditions in Fig. 5 are those that concern us most. For the state of affairs at the end is (provided that resistance and other losses are negligible) the same as at

the commencement. Therefore if a Hertz aerial is connected at the end the effect is the same as if it were connected directly on to the source, and the double line plays no part except that of a feeder. The effect

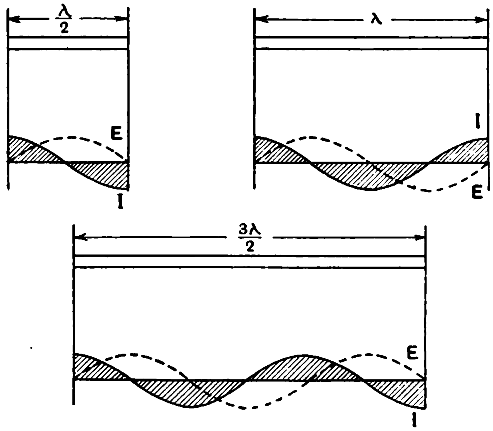

Fig. 5.

of resistance, either ohmic or due to radiation, etc., is to slow the velocity of transmission of the waves along the wires, so that the wavelength as measured along them is below the actual figure. This effect is not important in practical cases, but was detected in the experiments to be described. Also the distance apart of the wires is immaterial within wide limits, as by a happy circumstance the drop in inductance caused by bringing the wires closer is balanced by the corresponding rise in capacity.

Of course, it would be possible to upset the simple relations shown in the diagrams by inserting coils or condensers at any place, and in fact this is what happens at the input end where some form of inductance or capacity is necessary to couple to the source. Inductive coupling is most usual, and the electrical length of the line may conveniently be adjusted by a variable condenser, as this is a much more practical way of doing it than by cutting off or tacking on bits of wire. The reader will have gathered that it is necessary to work a Hertz aerial at a fixed wavelength depending on its length; or at most, a submultiple of this fundamental wavelength is allowable. Accordingly, if 45 metres is the wave chosen, the total length of the horizontal part of the aerial must be 22.5 metres, or alternatively 45 metres, 67.5 metres, etc. The feeder can then be any reasonable length, and adjusted electrically to fit the wave used.

The arrangement is then as shown in Fig. 6. The feeder should be as nearly as possible at right angles to the aerial to avoid unbalanced effects, but this is not essential to quite good results. The ammeter *A*, does not necessarily indicate the greatest current anywhere, as it may not be located at the maximum position, but *other things being equal* the greater the current, the more radiation from the aerial, and the meter therefore serves a useful purpose in tuning. The condenser, coupling, etc., should be adjusted for maximum current indicated, thus putting the feeder in tune. The aerial has already been put in tune by making it the correct length for the working wavelength. So in operating the transmitter, it is first carefully adjusted to generate the correct wavelength: the feeder is then brought into tune as above. The transmitter wavelength should then be checked again.

In order to confirm the above procedure, which was arrived at theoretically, some experiments were carried out on a reduced scale with wires about 5 feet from the ground

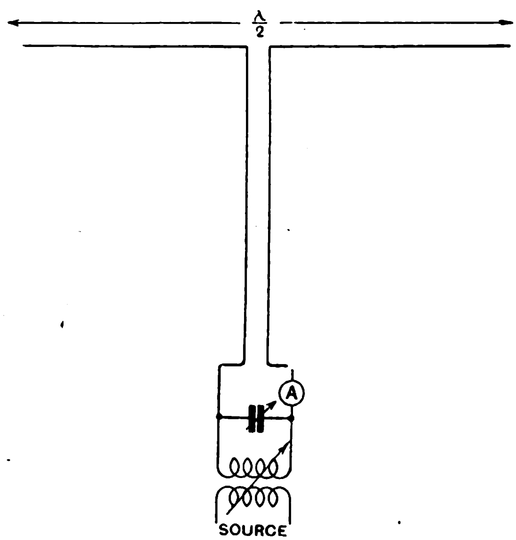

Fig. 6.

so as to allow ammeters to be inserted at various points. A simple Hartley circuit oscillator was used as source, and various coupling coils were used from 3 to 8 turns

on a 3 in. tube. The first arrangement tried had the dimensions indicated in Fig. 7. The aerial being 9.5 metres long should work at 19 metres, and experiments were made to find out if on this assumption the correct conditions would be obtained, *i.e.*, the maximum current at the centre of the aerial. It was found that with the ammeter at the

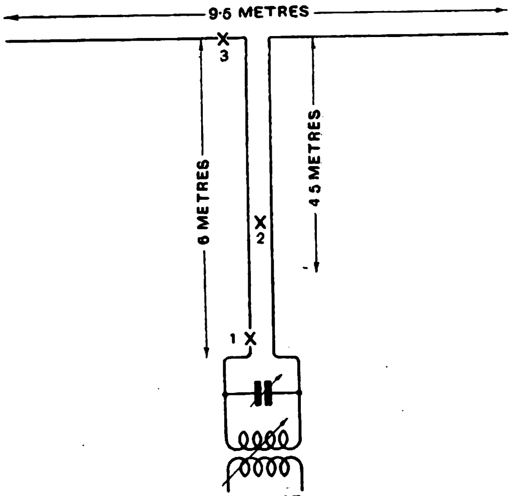

Fig. 7.

point (1) a maximum was obtained at 20 metres, and this current could be further increased by adjustment of the condenser. Further, it was found that this wavelength gave the maximum current whatever the initial value of the condenser. By placing the ammeter at point (3) it was found that the readings corresponded to those obtained at (1), though they were not equal. The drop in current due to working it at the wavelength corresponding to its physical length, *i.e.*, 19 metres, was trifling, as the resonance was not very sharp. A current several times larger than either of the preceding was noted by bridging the ammeter across at point (2).

The "aerial" was then removed, leaving the two parallel wires only. There was no resonance observed at (1) at 20 metres, but at 24 metres, or four times the length of the feeder. This corresponds to the case shown diagrammatically in the first example in Fig. 3.

The length of the "aerial" was altered to 7.5 metres and it then worked best on a little over 15 metres wave. Finally the feeder length was altered to 3.5 metres, and the working wavelength, *i.e.*, that which gave the maximum current at (1), was unaltered.

These experiments demonstrated clearly that one is justified in accepting the current reading at the input end as an indication of correct working, though its actual maximum value does not necessarily give the maximum aerial current.

A horizontal aerial 22.5 metres long and about 10 metres high has been erected, the feeder coming away to the side, as in Fig. 8. This is unavoidable, owing to the situation. The feeder wires are spaced 6 inches apart by thin ebonite strips. This system works on 45 metres and shows a great improvement over the inverted L aerial. It is also remarkably free from variations when swung about in the wind, even when no steps are taken to ensure constancy. Normally, however, the transmitter is run with quartz control. When used for reception, or transmission on other waves, the two feeders are joined at the lead-in and the aerial is used as T-type.

The recent low-power tests organised in November, 1926, by the R.S.G.B. have provided a good opportunity for obtaining practical data on the effectiveness of this aerial. The situation is such that results with other types of aerial have been extremely unsatisfactory, owing to high loss resistance and low radiation resistance. During the

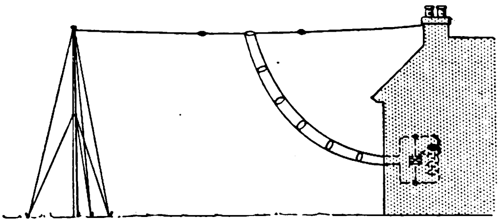

Fig. 8.

tests, using 4.8 watts input to the transmitter, two-way communication was established with America on more than one evening.

Mr. J. H. D. Ridley, operating British 5NN, after trying no less than five types of aerial with lack of success, also adopted the same form finally, and with the same power accomplished two-way working with 15 American stations during the week. It should be mentioned that both the aerials referred to lay north and south, and were thus favourably oriented for transatlantic working.

The Tucker Microphone for Reception.

By Prof. H. E. Watson, D.Sc.

(*Indian Institute of Science, Bangalore, India*).

THE Tucker microphone consists essentially of a very fine, electrically heated platinum wire placed across the neck of a Helmholtz resonator. Upon the incidence of a note of the same pitch as its own fundamental, the resonator responds and a vibrating current of air is produced in the neck, which cools the platinum wire, changing its resistance and giving rise to an alternating current superimposed upon the direct heating current. By means of a transformer and amplifier this alternating current may be separated and magnified sufficiently to produce a note in telephones or a loud speaker. This beautiful instrument has been described in great detail by W. S. Tucker and E. T. Paris,* one of its many useful features being its extraordinary selectivity. An example is given in the paper referred to showing that in one case, a change in the frequency of the incident note of 6 per cent., or roughly a semitone, was found to reduce the intensity of the received note to one-fifth of the previous value.

In consequence of this property it is quite possible to select any particular note from a complex sound and, if necessary, measure its intensity. It was therefore suggested by G. G. Blake† that the instrument might be of value in the reception of wireless messages. It also occurred to the author that the effect upon atmospherics might be considerable and with a view to testing this possibility a number of experiments were carried out.

In the original paper of Tucker and Paris most of the experiments recorded are for frequencies not exceeding 250 and it is pointed out that at higher frequencies the instrument is less sensitive.‡ As 250 is not a suitable frequency for audible reception, it was decided to try to obtain results at about 1,000 periods. This was found quite possible when a wire 0.0001 in. in diameter was used in conjunction with the resonator. The size of wire used by Tucker and Paris was ordinarily 0.00024 in. Improved results might have been obtained with still finer wires, but these proved somewhat difficult to mount and no attempt was made to find the optimum thickness.

Of the several possible ways of conveying the sound to the resonator, the simple one of building the telephone into the resonator itself was adopted. As the primary object of the research was not the design of the most efficient resonator, and as the instruments first constructed were found to be suitable, no further investigations into this side of the subject were made although there is considerable scope for work in this direction.

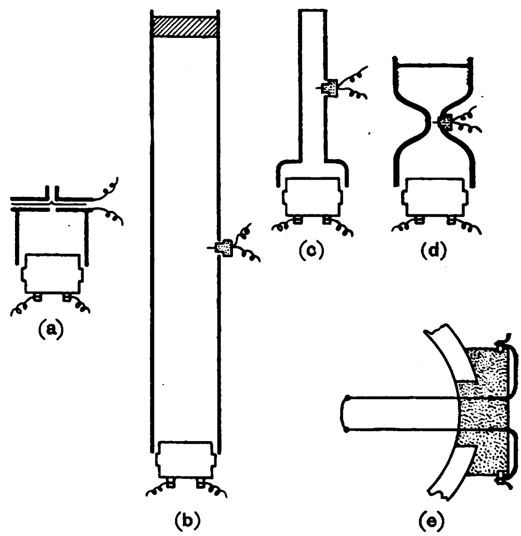

Fig. 1.

Fig. 1 shows four resonators which were constructed. (*a*) was of the Hughes pattern made of thick brass tube, 2 in. in diameter, with a bolted on cover insulated with mica and ebonite carrying a neck $\frac{5}{16}$ in. in diameter and $\frac{1}{2}$ in. long. A straight platinum wire instead of a grid was soldered to two discs of silver foil separated by mica. A Brown telephone receiver was cemented into the open end of the tube. The construction of this instrument was not simple, the

* *Phil. Trans.* 1921, 221, A, 389.
† *Wireless World*, 1924, 14, 316.
‡ Since the present experiments, microphones have been exhibited suitable for higher frequencies.

resistance of the platinum wire (about 400 ohms when hot) was rather high and the results obtained were not as good as with the resonators subsequently made. In these, the wire was soldered to two 40 S.W.G. Constantan wires mounted in an ebonite plug which could be inserted through a hole at the side of the resonator, the assembly being similar to that of a straight lamp filament. The arrangement is shown full size at (*e*) (Fig. 1). Constantan was used in order to secure rigidity while reducing the diameter as much as possible. The Wollaston wire was slightly curved before being soldered to the supports so that there should be no tension on the platinum when the silver coating was removed. Filaments of this type were comparatively easy to make if the soldering was done with an electrically heated wire. The filaments were $\frac{1}{8}$ in. long and worked quite well with a current of $15\mu A$ which was just insufficient to raise them to redness. The resistance with this current passing was about 120 ohms.

Resonators (*b*) and (*c*) were not of the Helmholtz type, but straight tubes closed at both ends. (*b*) was of glass 2 in. in diameter and 18 in. long, its fundamental frequency was 384 and the harmonic with three times this frequency was used as it was thought that shock excitation by atmospherics might tend to produce the fundamental which would not be so readily heard as the note of higher pitch. There was, however, no marked improvement. (*c*) was the simplest and perhaps the most satisfactory resonator tried. It was made from a thick brass tube $\frac{7}{8}$ in. in bore and 6 in. long enlarged at one end to receive the telephone. (*d*) was a double Helmholtz resonator of cast lead. The volume of the upper chamber could be adjusted by means of a brass plate which could be screwed up and down. Alternately a second telephone suitably adjusted as regards phase could be inserted at the top.

Most of the experiments were conducted with resonators (*c*) and (*d*) at a frequency close to 1,024. The general arrangement of the apparatus is shown in Fig. 2. *A* is a three valve receiver (1-v-1) with resistance capacity H.F. coupling, connected directly with an aerial 400 ft. long and 120 ft. high at the far end. This sufficed to bring in many of the high power stations at comfortable strength. *B* is a Mark C III. three valve audio-frequency amplifier which was screened to avoid local disturbances. The remaining connections are obvious from the diagram.

The apparatus was first tried in July, 1925, but as the monsoon had set in, the atmospherics, which are at their worst in April and May, had considerably subsided although still plentiful. It is, unfortunately, not possible to give quantitative figures for the effects observed, but the outstanding features were the apparent great reduction of the atmospheric-signal strength ratio and the reception of the usual crashes as a musical note. The effect upon aural reception was that although letters might be misread owing to mutilation

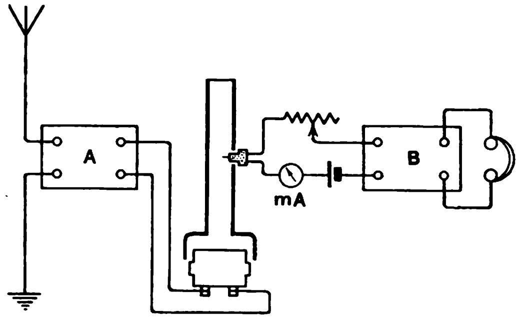

Fig. 2.

by atmospherics, the ear was not rendered insensitive by the crashes and reception was greatly facilitated. Further observations were made during a heavy local thunderstorm in October, 1925, when it was impossible to wear the headphones without great discomfort. On this occasion an ordinary type of telephone was used in resonator (*d*) and the atmospherics were barely detectable. This was partly accounted for by the lower sensitiveness of the combination, the final signal being distinctly weaker than the one obtained from the receiver alone, whereas in the previous experiments the two were of approximately the same intensity. The conclusion, however, is the same, viz., that very decided advantages are to be obtained by the use of the instrument.

An experiment was next conducted to gain some idea as to the performance of the instrument at the higher signalling speeds. A specially constructed rotating contact connected with a variable speed motor was made to send Vs on a local oscillator and these were received on the apparatus. Up to about 140 r.p.m., *i.e.*, 28 words a minute,

the dots were clearly received, but above this speed they became somewhat blurred. The dashes remained audible at much higher rates. At 150 r.p.m. the duration of a dot is $\frac{1}{30}$ second, in which period the air in the resonator would execute about 33 complete vibrations. The exact number of vibrations necessary for the air to attain its maximum displacement will depend very much on the design of the resonator. If the damping is slight, the signal will build up rapidly in strength and a high speed will be attainable; on the other hand, if the damping is considerable, a single, very rapid impulse on the telephone diaphragm, such as might be produced by certain types of atmospheric, will have little effect when compared with that produced by the series of small impulses from the signal. In the experiment under consideration no attempt was made to separate the time constant of the resonator from that of the rest of the apparatus, so that the blurring may have been due to the latter and the performance of the resonator may have been better than has been indicated.

Finally, a few words may be said as to the selectivity of the microphone as experimentally determined. The apparatus was not suitable for quantitative measurements by the Wheatstone bridge method and so the experiments were merely qualitative. It may be mentioned, however, that they are the order which would be expected if the resonance curve at a frequency of 1,000 were similar to the one given by Tucker and Paris for 250 periods.

In one experiment, Madras (VWO) working on 4,000 metres was tuned in on the receiver already mentioned, which is perhaps as unselective as possible, autodyne reception being used. A local oscillator was arranged to transmit Vs on a near wavelength so that the signals received were much weaker than those from VWO. Tuning was carried out by means of a vernier condenser. When VWO was tuned in the Vs were almost inaudible; when the local oscillator was tuned in, the signals from VWO were audible but not loud enough to interfere with accurate reading. The change in the capacity of the condenser between the two settings was $6\mu\mu F$ on a total of $1,660\ \mu\mu F$, say 1 in 250 corresponding with a change in frequency of 1 in 500, *i.e.*, 150 cycles for the frequency of 75kC employed. The corresponding difference in the wavelengths of the two transmissions is only 8 metres. As it is the difference in frequency which determines the change in pitch of the beat note, it is this quantity, which we will assume to be about 150 cycles for signals not differing very widely in intensity, which determines the possibility of separating two signals whatever the operating frequency. Expressed in wavelengths, a separation could be effected of two stations working not less than 200 metres apart at 20,000 metres or 0.02 metre apart at 200 metres. By using a beat note of lower frequency, still sharper separation could be obtained, but, as already pointed out, other factors render this inadvisable.

Data regarding the performance of tuned audio-frequency transformers appear to be scanty. Reference, however, may be made to a recent paper on the subject by A. Pagès.* From the one resonance curve given, the selectivity of the transformers described appears to be considerably inferior to that of the hot wire microphone.

The effect of the microphone upon the confused noises usually heard when receiving upon the longer wavelengths with an unselective receiver, is striking. With perhaps a few exceptions, each station may be tuned in separately and clearly. For example, no trace of the strong signals from Saigon (HZA 15,750 metres) or Malabar (PKX 15,600 metres could be heard when listening to Lyon (YN 15,300 metres). The author has not had an opportunity of trying the apparatus in Europe, or it would no doubt be possible to give instances of the separation of signals differing still less in frequency. In very many cases, therefore, it is possible to dispense with elaborate high frequency filters which tend to weaken the signals and to use in their place a comparatively simple note magnifier. The chief drawback to the commercial use of the hot wire microphone is perhaps its fragility. Its average life has not been determined but should be considerable at the comparatively low temperature employed, moreover, filaments made as described can be replaced in a few minutes and may be handled with ordinary care. The experiments described are intended only to illustrate the possibilities of the instrument and a more extensive investigation should give greatly improved results.

* *L'Onde Electrique*, 1926, June, pp. 275-283.

Further Notes on Simple Resonance Curves.

By Prof. E. Mallett, D.Sc., M.I.E.E.

IN the present article the resonance curves that are obtained under different conditions when two circuits are coupled together either magnetically or by a condenser are considered for the cases which give simple resonance curves. It is shown that the curves may be either of the ordinary type or the rather more complicated type obtained when the pole of the resonance circle, instead of lying on the circumference, lies outside the circle. Various applications of these "wiggle" resonance curves are described.

The subject is considered under the following headings :—

1. One circuit tuned, coupling by mutual inductance, either ω or C varied.
2. The same with condenser coupling.
3. Two circuits tuned, coupling by mutual inductance, the condensers varied.
4. The dynamometer effect.
5. Applications.

1. Coupling by Mutual Inductance.

Let us first consider the circuit of Fig. 1, in which an anode inductance of impedance $Z_1=R_1+j\omega L_1$ is coupled by a mutual inductance M with an oscillatory circuit of impedance $Z_2=R_2+j(\omega L_2-1/\omega C_2)$. If e_g is the voltage of angular frequency ω applied to the grid of the valve, μ the amplification factor and R_a the anode impedance or differential resistance (as suggested in an Editorial), we have for the anode current i_a and the current in the secondary i_2 the equations

$$\left.\begin{aligned}\mu e_g&=(R_a+Z_1)i_a+j\omega Mi_2\\ 0&=Z_2 i_2+j\omega Mi_a\end{aligned}\right\} \quad \cdots \quad (1)$$

whence

$$i_a=\frac{\mu e_g}{R_a+Z_1+\dfrac{\omega^2M^2}{Z_2}} \quad \cdots \quad (2)$$

and

$$i_2=-\frac{j\omega M\mu e_g}{Z_2(R_a+Z_1)+\omega^2M^2} \quad (3A)$$

$$=-\frac{j\omega M\mu e_g/(R_a+Z_1)}{Z_2+\dfrac{\omega^2M^2}{R_a+Z_1}} \quad (3)$$

Let us now suppose that either the condenser C_2 or the angular frequency ω is varied round about resonance. If C_2 is varied the whole of the quantities in equation 3 remain constant except Z_2, and if ω is varied this is in effect nearly true over the resonance range, since this is covered with only a very small change in ω. It is clear therefore that a simple resonance curve will result for i_2 plotted against C_2 or ω, but that both the decay factor and to a small extent the resonance frequency of the

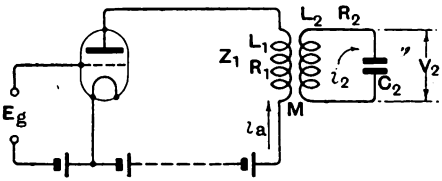

Fig. 1. *The voltage across the anode coil describes a "wiggle" resonance curve as the frequency or the secondary condenser is varied through resonance.*

oscillatory circuit Z_2 will be modified by the presence of the valve. This appears from the denominator of 3, which may be written

$$Z_2+\frac{\omega^2M^2}{(R_a+R_1)^2+\omega^2L_1^2}(R_a+R_1-j\omega L_1)$$

Generally speaking the square of the differential resistance R_a of the valve will be far greater than $\omega^2L_1^2$, and R_a will be far greater than R_1, so we may write for the denominator of 3

$$R_2+\frac{\omega^2M^2}{R_a}+j\left\{\omega\left(L_2-\frac{\omega^2M^2L_1}{R_a^2}\right)-\frac{1}{\omega C_2}\right\} (4)$$

Thus the effective inductance of the oscillatory circuit is decreased a little and the resonant ω is

$$\omega_0=\frac{1}{\sqrt{\left(L_2-\dfrac{\omega^2M^2L_1}{R_a^2}\right)C_2}} \quad (5)$$

This alteration will generally be very small so that the effective decay factor is obtained from (4) as

$$\Delta^1=\frac{R_2+\dfrac{\omega^2M^2}{R_a}}{2L_2}=\frac{R_2}{2L_2}+\frac{\omega^2M^2}{2R_aL_2} \quad (6)$$

We are interested in obtaining the largest possible voltage across C_2, which means the largest possible value of i_2, and it is clear from (3) that if M is made too great the current i_2 will actually be smaller than with a smaller value of M. The best value of M is obtained by differentiating 3A with regard to M and equating to zero. Thus

$$\frac{di_2}{dM} = -j\omega\mu e_g\left\{\frac{1}{Z_2(R_a+Z_1)+\omega^2M^2} - \frac{2M^2\times\omega^2}{\{Z_2(R_a+Z_1)+\omega^2M^2\}^2}\right\}$$

Equating this to zero gives

$$Z_2(R_a+Z_1)+\omega^2M^2 = 2\omega^2M^2$$

which at the resonant frequency, when $Z_2=R_2$, and neglecting Z_1 in comparison with R_a, gives $\omega^2M^2=R_aR_2$,

or $$M = 1/\omega\sqrt{R_aR_2} \quad .. \quad (7)$$

as the value of the mutual inductance to give the largest possible value of current in the oscillatory circuit.

With this value of the mutual inductance the effective decay factor from (6) becomes

$$\Delta' = \frac{R_2}{2L_2}+\frac{R_2}{2L_2} = 2\Delta_2$$

The decay factor of the valve circuit is double that of the oscillatory circuit alone and this is the decay factor that would be obtained from a resonance curve of i_2 plotted against ω. This increase of decay factor is of great importance in measurements of high frequency resistance by drawing a resonance curve, or by adding resistances to the oscillatory circuit. It is only when M is very small so that ω^2M/R_a^2 is negligible compared with R_2 that the method can succeed, and this involves either a very powerful amplifier valve or very delicate measuring instruments. If the measurement is attempted by coupling direct to an oscillator the difficulty is accentuated, as now R_a must be replaced by the effective impedance of the circuit to which the oscillatory circuit is coupled, and this will generally be far smaller than the differential resistance of the valve.

Let us now consider the voltage across the anode coil Z_1 as the frequency is varied. The effective impedance of the coil is

$$Z_1 + \frac{\omega^2M^2}{Z_2},$$

and the current through it is i_a as given by 2. The voltage v_1 across it is therefore

$$v_1 = \frac{\mu e_g}{R_a+Z_1+\frac{\omega^2M^2}{Z_2}}\times\left(Z_1+\frac{\omega^2M^2}{Z_2}\right) \quad (8\text{A})$$

Now usually we may neglect the effective impedance of the coil in comparison with R_a and write

$$v_1 = \frac{\mu e_g}{R_a}\left\{Z_1+\frac{\omega^2M^2}{Z_2}\right\} \quad .. \quad (8)$$

The vector diagram of this equation is easily constructed. $1/Z_2$ is, as has been seen before, a circle traversed in a clockwise direction as ω is increased, and since the ω changes over resonance are very small, ω^2M^2 is to all intents and purposes constant, so that multiplying the circle $1/Z_2$ by ω^2M^2 merely changes the scale. The addition of Z_1 is effected by choosing a new pole O_1 so that $O_1O=Z_1$. This is done in Fig. 2(a), where OPR is the circle ω^2M^2/Z_2 and $O_1O=Z_1$, so that O_1P is the vector sum of O_1O and OP, *i.e.*,

$$O_1P = Z_1+\frac{\omega^2M^2}{Z_2}$$

for the particular value of ω considered. Multiplication by $\mu e_g/R_a$ merely alters the scale. If now we measure the values of the

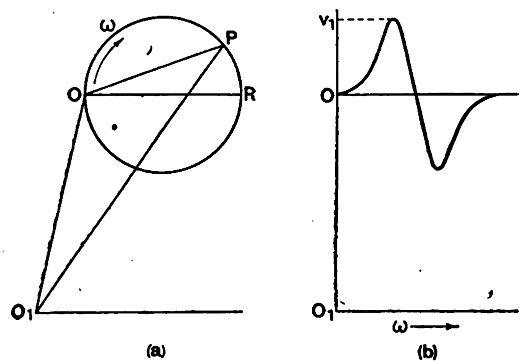

Fig. 2. *Showing how the wiggle curve is derived from a circle on a stick.*

voltage across the coil Z_1 and plot them against ω we shall obtain the curve of Fig. 2(b), which is drawn by measuring the values of O_1P for various positions of P and therefore for various values of ω. We have obtained another type of simple resonance curves. It is called simple still since only one tuned (or nearly tuned)

circuit is involved. If two tuned circuits were involved we might call the resulting resonance curves compound, if three, triple, and so on. If a large number, as in a filter or chain conductor, the term chain resonance curves might be suitable.

This curve of Fig. 2(b) is very interesting, because it is derived from a circle whose damping is that of the secondary circuit alone, and is not influenced, except to a small degree, by the associated valve circuit. This is the case under the conditions contemplated in Fig. 2, where ω^2M^2/R_2 $(=OR)$ is of the same order as Z_1 $(=O_1O)$, and both are small compared with R_a.

If the curve of Fig. 2(b) is obtained experimentally it is possible by a simple construction to find the vector diagram of Fig. 2(a), and hence from the circle of Fig. 2(a) to find the $\omega/\tan\phi$ line as described in a recent article.* This line then will give the decay factor of the secondary circuit.†

2. Capacity Coupling.

The same type of "wiggle" resonance curve is obtained with direct coupling with

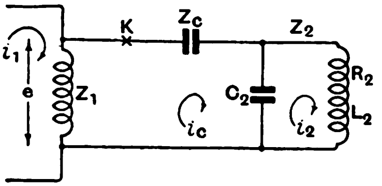

Fig. 3. *The case of coupling by condenser. Wiggle curves are obtained when the frequency, the coupling condenser or the tuning condenser are varied.*

a condenser, as indicated in Fig. 3. Then if i_1, i_c, and i_2 are the circuital currents, and e is the voltage maintained across Z_1, and

$$Z_c = -\frac{j}{\omega C_c}$$

is the coupling impedance, we have the following equations :—

$$\left.\begin{aligned} e &= Z_1(i_1 - i_c) & \text{(i)} \\ O &= Z_1(i_c - i_1) + Z_c i_c - \frac{j}{\omega C_2}(i_c - i_2) & \text{(ii)} \\ O &= Z_2 i_2 + \frac{j}{\omega C_2}\, i_c & \text{(iii)} \end{aligned}\right\} \quad (9)$$

Eliminating i_1 and i_2 from (ii) by means of (i) and (iii) we obtain

$$i_c = \frac{e}{Z_c - \dfrac{j}{\omega C_2} + \dfrac{j}{\omega^2 C_2^2 C_2}}$$

Now
$$-\frac{j}{\omega C_2} + \frac{1}{\omega^2 C_2^2 Z_2} = \frac{-j\omega C_2(Z_2) + 1}{\omega^2 C_2^2 Z_2}$$

$$= \frac{-j\omega C_2(R_2 +)\left(\omega L_2 - \dfrac{1}{\omega C_2}\right) + 1}{\omega^2 C_2^2 Z_2}$$

$$= \frac{\omega^2 L_2 C_2 - j\omega C_2 R_2}{\omega^2 C_2^2 Z_2}$$

$$= L_2/C_2 Z_2$$

neglecting R_2 in comparison with ωL_2.

Thus

$$i_c = \frac{e}{Z_c + \dfrac{L_2}{C_2 Z_2}} \quad \dots \quad \dots \quad (10)$$

and using this in 9 (i) and (iii) we obtain

$$i_1 = e\left\{\frac{1}{Z_1} + \frac{1}{Z_c + \dfrac{L_2}{C_2 Z_2}}\right\} \quad \dots \quad (11)$$

$$i_2 = -\frac{je}{\omega C_2 Z_2 Z_c + \omega L_2} \quad \dots \quad (12)$$

The current into the network is i_1 and the voltage across the coil Z_1 is e, so that the effective impedance is $Z' = e/i_1$, which from (ii) is

$$Z' = \frac{1}{\dfrac{1}{Z_1} + \dfrac{1}{Z_c + \dfrac{L_2}{C_2 Z_2}}} \quad \dots \quad (13)$$

Considering the quantity

$$Z_c + \frac{L_2}{C_2 Z_2},$$

whose value will fluctuate considerably with frequency changes, we see that the resonance phenomenon will occur when Z is of the same order as L_2/C_2Z_2. In Fig. 4 the circle OPQ is the locus of L_2/C_2Z_2, with diameter $= L_2/C_2R_2$

and
$$O_1O = Z_c = -\frac{j}{\omega C_c},$$

so that

$$O_1P = O_1O \mathbin{+\!\!\!+} OP = Z_c + \frac{L_2}{C_2 Z_2} \quad *$$

* E. Mallett, *E.W. & W.E.*, Feb., 1927, p. 93.

† Details of how this measurement may be carried out are given in the *Journal of the Institution of Electrical Engineers*, Vol. 63, pp. 397-412.

* The $\mathbin{+\!\!\!+}$ sign is used for vector addition.

and the smallest value of O_1P occurs when P is at A, so that O_1A produced passes through the centre of the circle. The value of O_1P is then a minimum O_1A.

Inverting from O_1 to obtain

$$\frac{1}{\left(Z_c + \frac{L_2}{C_2 Z_2}\right)}$$

in 13, the circle $O_1P'D$ is obtained (Fig. 5(a), and the addition of $1/Z_1$ is carried out by choosing a new pole, O_2, such that $O_2O_1 = 1/Z_1$; then $O_2P' = 1/Z_1$, the circle being described clockwise from somewhere near O_1 as ω is increased, or as C_2 is increased.

It is clear that the curve of $1/Z'$ plotted against ω or C_2 is a wiggle curve drawn in the reverse direction from that of Fig. 2(b).

Resonance will occur, *i.e.*, P' will lie on D in Fig. 5 (a) or P on A in Fig. 4 very nearly when $|OO_1| = |OA|$, especially when C_c is large enough to make OO_1 small, which is the interesting case. That is, resonance occurs when

$$\left|-\frac{j}{\omega C_c}\right| = \left|\frac{L_2}{C_2 Z_2}\right|$$

or

$$\frac{1}{\omega C_c} = \frac{L_2}{C_2\sqrt{R_2^2 + \left(\omega L_2 - \frac{1}{\omega C_2}\right)^2}}$$

Now when OO_1 is small OA is nearly vertical,

$$\left(\omega L - \frac{1}{\omega C}\right)^2$$

is large compared with R_2^2 and we have

$$\frac{1}{\omega C_c} = \frac{L_2}{C_2\left(-\omega L_2 + \frac{1}{\omega C_2}\right)} \quad * \qquad (14A)$$

or

$$\omega_A = \frac{1}{\sqrt{L_2\left(1 + \frac{C_c}{C_2}\right)C_2}} \qquad (14)$$

It is seen that the resonance frequency is lower than that of the secondary circuit alone. The effective inductance of the circuit has been increased to

$$L_2\left(1 + \frac{C_c}{C_2}\right),$$

with the result that the frequency has been lowered. The effective decay factor is also lowered. The circle of Fig. 5 has been drawn as the inverse of the impedance,

$$\left(Z_c + \frac{L_2}{C_2 Z_2}\right)$$

which is equal to

$$-\frac{j}{\omega C_c} + \frac{L_2\left\{R_2 - j\left(\omega L_2 - \frac{1}{\omega C_2}\right)\right\}}{C_2 R_2^2 + \left(\omega L_2 - \frac{1}{\omega C_2}\right)^2\}}$$

$$= \frac{L_2 R_2}{C_2\left(\omega L_2 - \frac{1}{\omega C_2}\right)^2} - j\frac{L_2}{C_2\left(\omega L_2 - \frac{1}{\omega C_2}\right)} - \frac{j}{\omega C_c}$$

$$= \frac{L_2 R_2}{C_2\left(\omega L_2 - \frac{1}{\omega C_2}\right)^2} - j\frac{\omega L_2\left(1 + \frac{C_c}{C_2}\right) - \frac{1}{\omega C_2}}{\omega C_c\left(\omega L_2 - \frac{1}{\omega C_2}\right)}$$

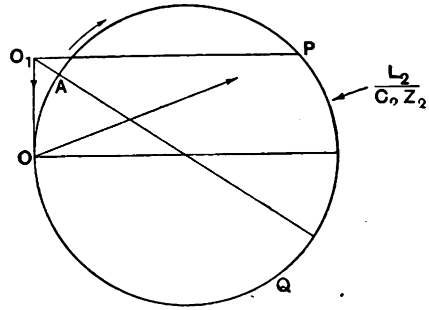

Fig. 4. *Circle diagram of condenser coupling.*

The effective decay factor of this impedance is therefore

$$\Delta' = \frac{\dfrac{L_2 R_2}{C_2\left(\omega L_2 - \frac{1}{\omega C_2}\right)^2}}{-2\cdot\dfrac{\omega L_2\left(1 + \frac{C_c}{C_2}\right)}{\omega C_c\left(\omega L_2 - \frac{1}{\omega C_2}\right)}}$$

$$= \frac{R_2}{2L_2\left(1 + \frac{C_c}{C_2}\right)} \quad \ldots \quad \ldots \quad (15)$$

since by 14A

$$-\left(\omega L_2 - \frac{1}{\omega C_2}\right) = \frac{L_2}{C_2}\omega C_c$$

at resonance, and this holds nearly in the neighbourhood of resonance.

These conclusions have been confirmed experimentally. An oscillator-amplifier was

* The $-ve$ sign is taken in extracting the root to make the right-hand side positive.

used to pass current through Z_1 and the voltage v across Z_1, was measured by a valve voltmeter. Then the circuit to the condenser was broken at K, Fig. 3, and the voltage v_1 across Z_1 measured again. On the assumption that the amplifier valve differential

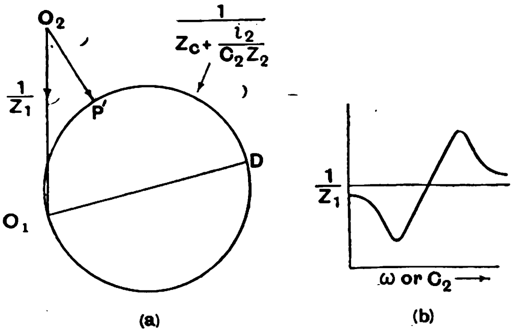

Fig. 5. *Showing how the wiggle curve is obtained with condenser coupling.*

resistance was so large that the current i_1 remained the same for the two readings, we have

$$i_1 = v\left(\frac{1}{Z_1} + \frac{1}{Z_c + \frac{L_2}{C_2 Z_2}}\right)$$

and $\quad i_1 = v_1 \,.\, 1/Z_1$

whence $$\frac{v_1}{v} = 1 + \frac{Z_1}{Z_c + \frac{L_2}{C_2 Z_2}} \quad .. \quad (16)$$

which gives the vector diagram of Fig. 5 (a), multiplied by $|\ Z_1\ |$ and turned through nearly 90°.

Thus if ω is varied and v_1/v plotted against ω, or against the oscillator vernier condenser which is used to vary the frequency, the construction referred to before can be used to obtain the circle diagram and hence the value of Δ'.

This is done in Fig. 6. The values of the inductances and condensers were

$L_1 = 700\mu$H, $L_2 = 4{,}040\mu$H, $C_2 = 855\mu\mu$F, $C_c = 146\mu\mu$F.

The secondary coil used in this experiment was one whose resistance at about $\omega = .5 \times 10^6$ had been measured carefully on several occasions and found to be very nearly 9 ohms. In the present experiment the condenser C_2 was adjusted until resonance occurred at the same frequency. To do this it was found necessary to make C_2 $855\mu\mu$F, which with $10\mu\mu$F self capacity of L_2 gives for the secondary capacity $865\mu\mu$F. Then from 14 the resonant frequency should be

$$\omega_A = \frac{1}{\sqrt{L_2 C_2\left(1 + \frac{C_c}{C_2}\right)}}$$

$$= \frac{1}{\sqrt{4{,}040 \times 10^{-6} \times 865 \times 10^{-12} \times (1 + 146/865)}}$$

$$= .495 \times 10^6$$

which is quite close to that actually found.

From Fig. 6 the slope of the $c \tan \alpha$ line is found to be 23.0. Since for the oscillators used $\delta\omega = 42.6\ C$, we have for the decay factor $\Delta' = 23.0 \times 42.6 = 980$.

From 15 this is

$$R_2/2L_2\left(1 + \frac{C_c}{C_2}\right)$$

hence

$$R_2 = 2\Delta' L_2\left(1 + \frac{C_c}{C_2}\right)$$

$$= 2 \times 980 \times 4{,}040 \times 10^{-6} \times 1.169$$

$$= 9.24 \text{ ohms}.$$

in fairly close agreement with the 9 ohms previously found.

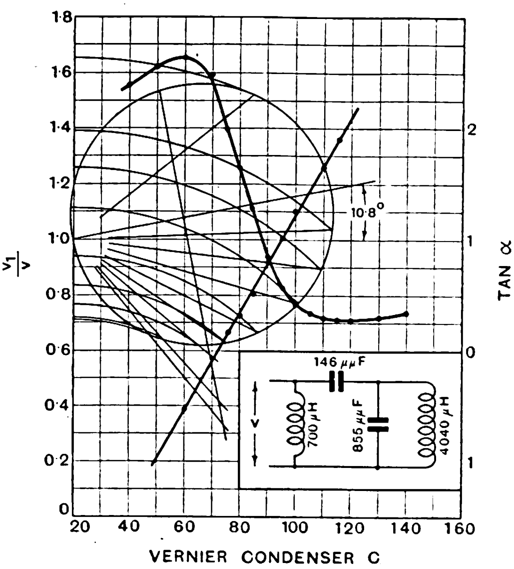

Fig. 6. *An experimentally obtained curve, showing the straight line and circle construction for the decay factor.*

The value of the secondary current is determined from equation 12

$$i_2 = -\frac{je}{\omega C_2 Z_2 Z_c + \omega L_2} \quad .. \quad (12)$$

This gives in the case of capacity coupling a vector diagram as in Fig. 7. The straight line Z_2 (pole O) is turned through a right angle clockwise by multiplication by

$$\omega C_2 Z_c = -j\frac{C_2}{C_c}$$

and its pole is shifted to O_1 on adding ωL_2. Inverting the circle O_1D is obtained to represent $1/(\omega C_2 Z_2 Z_c + \omega L_2)$ and finally i_2/e, the secondary current per volt across the network is found by turning this circle clockwise through a right angle. The arrows show the direction in which the locus is traversed as ω increases starting from a very small value.

Maximum secondary current occurs when $\omega L_2 + \omega C_2 Z_c X_2 = 0$

giving $$\omega^2 = \frac{1}{L_2 C_2\left(1 + \frac{C_c}{C_2}\right)}$$

as before.

The resonance curve is obtained from the circle O_1D' and is evidently an ordinary

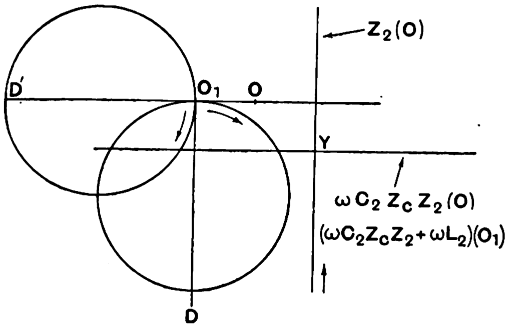

Fig. 7. *The secondary current vector diagram.*

simple resonance curve. The decay factor is easily shown, as in the case of the wiggle curve, to be

$$\frac{R_2}{2L_2\left(1 + \frac{C_c}{C_2}\right)}$$

If ω is kept constant and C_2 or C_c is varied the vector loci and resonance curves obtained are similar to those obtained when ω is varied. This is clear on reference to Fig. 4. If C_2 is varied P moves along the arc OAP just as it did when ω was varied, while if C_c is varied, O_1 moves along the line OO_1 and the ray is drawn from A to O_1. The actual vector changes are similar therefore in this case also.

3. Two Tuned Circuits.

If we have two tuned coupled circuits, and the condensers of the circuits are varied, simple resonance curves result which may be of either the ordinary or the wiggle type.

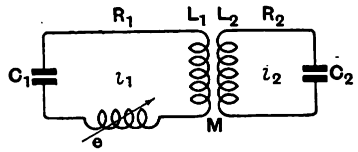

Fig. 8. *Two coupled circuits in which either of the condensers can be varied.*

Consider the circuit of Fig. 8 in which an E.M.F. e is introduced into the first. For the E.M.F. equations in the two circuits we have

$$e = Z_1 i_1 + j\omega M\, i_2$$
$$0 = Z_2 i_2 + j\omega M\, i_1$$

whence

$$i_1 = \frac{e}{Z_1 + \frac{\omega^2 M^2}{Z_2}} = \frac{e}{Z'} \quad .. \quad (17)$$

$$i_2 = \frac{e}{j\omega M - \frac{Z_1 Z_2}{j\omega M}} = \frac{e}{Z''} \quad .. \quad (18)$$

where Z' and Z'' are effective impedances for the primary and secondary currents respectively, defined by

$$\left.\begin{aligned} Z' &= Z_1 + \frac{\omega^2 M^2}{Z_2} \\ Z'' &= \frac{j}{\omega M}(Z_1 Z_2 + \omega^2 M^2) \end{aligned}\right\} \quad (19)$$

(i) Primary condenser varied.

In the expression for Z' varying C_1 will alter Z_1 without affecting the second term. The locus of Z' is found in Fig. 9. The vertical straight line CC' with pole O is the locus of Z_1, and the constant vector $\omega^2 M^2/Z_2$ is added by making $O_1O = \omega^2 M^2/Z_2$. Then the straight line with pole O_1 represents Z' and inverts to a circle to give the locus of i_1. The i_1/C_1 curve therefore appears as an ordinary simple resonance curve.

If Z_2 at the frequency in question has a positive angle (the frequency above the resonance of Z_2) ω^2M^2/Z_2 has a negative angle, $O'O$ is drawn below the horizontal, the resonant frequency of Z' is lower than that of Z_1, and a larger condenser is necessary to tune. This is the case in Fig. 9, where the condenser value has increased as is indicated by c for resonance moving to c'. If Z_2 has a negative angle the resonant frequency of Z' is higher than that of Z_1 and a smaller condenser value is required. If Z_2 is tuned the resonant frequencies of Z_1 and Z' (as well as Z_2) are the same.

$$O_1c' = O_1O \cos \widehat{OO_1C'} + OC$$
$$= \left|\frac{\omega^2M^2}{Z_2}\right| \cdot \left|\frac{R_2}{Z_2}\right| + R_1$$
$$= \frac{\omega^2M^2}{R_2^{\,2}+\left(\omega L_2 - \dfrac{1}{\omega C_2}\right)^2} \,.\, R_2 + R_1 = R',$$

the effective resistance of the primary circuit.

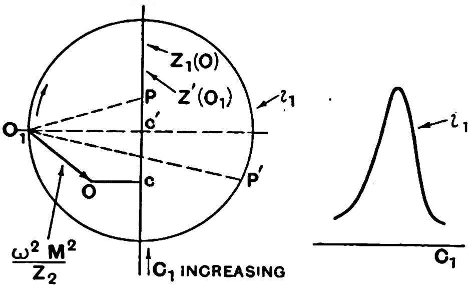

Fig. 9. *Diagram for variations of the primary current with variations of the primary condenser.*

$$\tan a = \frac{CP - CC'}{O_1C'} = \frac{\left(\omega L_1 - \dfrac{1}{\omega C_1}\right) - \left(\omega L_2 - \dfrac{1}{\omega C_2}\right)}{R'}$$

and writing $\omega_1^{\,2} = 1/L_1C_1$ so that $C_1 = 1/\omega_1^{\,2}L_1$,

$$\frac{d \tan a}{d\omega_1} = -2\frac{\omega_1 L_1}{\omega R}$$

If the frequency is nearly that of the primary circuit resonant frequency, so that $\omega \doteqdot \omega_1$ then

$$\frac{d\omega_1}{d \tan a} = \frac{R'}{2L_1}$$

and the circle and straight line construction carried out on a curve of i_1 plotted against ω_1 will give the effective resistance R'.

If i_1 is plotted against c_1 we obtain

$$\frac{d \tan a}{dC_1} = \frac{1}{\omega C_1^{\,2}R'} \doteqdot \frac{1}{C_1R'}\sqrt{\frac{L_1}{C_1}}$$

and

$$\frac{dC_1}{d \tan a} = R'C_1\sqrt{\frac{C_1}{L_1}}$$

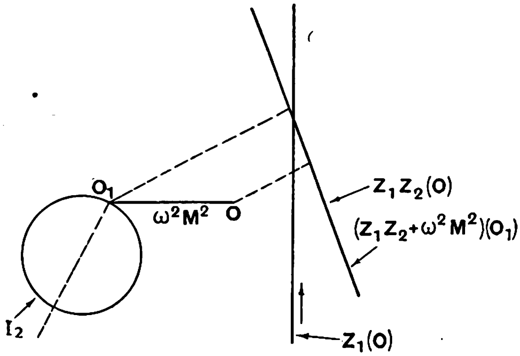

Fig. 10. *Diagram for variations of the secondary current with variations of the secondary condenser.*

which enables R' to be obtained from the slope of the line at resonance.

The secondary current will also give a simple resonance curve. For

$$Z'' = j\frac{\omega^2M^2 + Z_1Z_2}{\omega M} \qquad \text{(from 19)}$$

Multiplying the vertical line Z_1 by the constant Z_2 and adding ω^2M^2 shifts the pole from O to O_1. Multiplying again by $j/\omega M$ turns the line through 90° counter-clockwise and this inverted gives a circle. See Fig. 10.

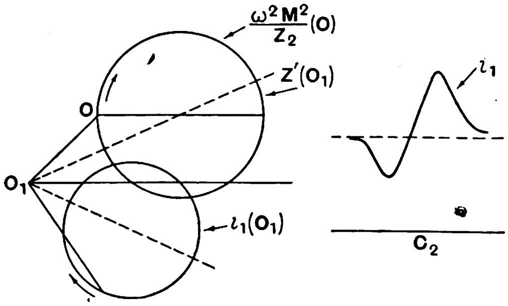

Fig. 11. *Diagram for the variations of the primary current with variations of the secondary condenser.*

(ii) *Secondary Condenser Varied.*—When the secondary capacity C_2 is varied exactly the same conditions apply for Z'' and i_2 as when the primary condenser is varied, since the expression for Z'' is symmetrical with regard to Z_1 and Z_2.

But the i_1 curve has a different form.

$$Z' = \frac{\omega^2 M^2}{Z_2} + Z_1$$

Z_2 is now the varying vector, and the locus of $\omega^2 M^2 / Z_2$ is a circle with pole O on the circumference. Adding Z_1 shifts the pole to

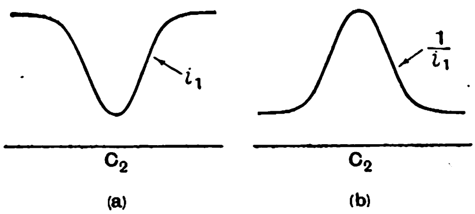

Fig. 12. *The special case of a tuned primary.*

O_1 fixed by making $O_1O = Z_1$. The locus of Z' is therefore a circle with the pole outside, and inversion to find i_1 gives another circle with pole outside. The curve of i_1 plotted against C_2 or ω_2 has the form therefore shown in Fig. 11.

In the special case when Z_1 is tuned so that O_1O is horizontal, the current curve is as shown in Fig. 12 (a), while the curve of $1/i_1$ is as shown in Fig. 12 (b).

In any case a curve of $1/i_1$, plotted against ω_2 is proportional to Z_2, the circle of which depends only on Z_2. The circle and straight line construction carried out on such a curve will therefore give the decay factor and hence the resistance of the secondary circuit alone. The scheme would be very similar to the "ammeter method" previously described.*

4. Dynamometer Effect.

A curve similar to these wiggle resonance curves is obtained by Mandelstam and Papalexi† by causing the currents from a primary and a secondary circuit to act on the fixed and the moving coil respectively of a dynamometer, as indicated in Fig. 13 (a), and plotting the deflection of the moving coil against the value of the condenser in the secondary circuit. The resulting curve is as shown at Fig. 13 (b). The primary is tuned to the source of supply, and the deflection is zero when the secondary is also tuned.

* *J.I.E.E.* Vol. 63, pp. 397-412.
† See *Jahr.* 4, 605, 1911, or *Ann. der Physik*, 33, 490.

The curve between the maximum deflections in the two directions is steeper the smaller the decay factors of the circuits. This effect was used for the precise measurement of frequency and for the measurement of the sum of the decay factors of the two circuits. The actual deflection for any setting of C_2 is proportional to $I_1 I_2 \cos\phi$, where I_1 and I_2 are the root mean square values of the currents and ϕ the phase angle between them. The mathematics is more complicated therefore than that in the cases we have considered. The curve, though similar to the wiggle curve, is not derived from a straight line and circle.

5. Applications.

(i) The application of the wiggle curve with mutual inductance coupling (Section 1) to the accurate determination of high frequency resistance and wavelength has

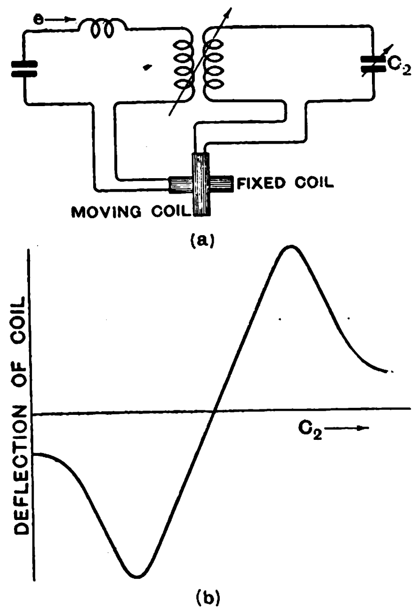

Fig. 13. *The dynamometer effect of Mandelstam and Papalexi.*

already been described in detail, as mentioned before. Further experience has proved frequency determinations made in this way to be of value, but unless an accurate resistance measurement is required the labour of the graphical construction does rather rule this method out.

The capacity coupling wiggle curve however can readily be used for the rapid examination of coils for both resistance and inductance, although the accuracy obtained will not be of such a high order. A circuit is set up as in Fig. 3, supplied by a valve oscillator-amplifier arrangement and with a valve voltmeter for measuring the voltages across Z_1. The oscillator is set to the desired frequency, the coil to be examined placed across C_2 (L_2 in the figure) and the calibrated condensers C_c and C_2 adjusted until a reasonable wiggle is obtained on the valve voltmeter as C_2 is varied. Then, knowing the frequency, the value of L_2 is found at once from equation 14, the value of C_2 used being that at the middle of the wiggle, when the same voltmeter deflection is obtained with the key K open or closed. Then readings of the valve voltmeter are made at the maximum voltmeter reading and the minimum v' and v'' respectively with the key closed and v_1' and v_1'' with the key open. The difference of the ratios, *i.e.*,

$$\frac{v_1'}{v'} - \frac{v_1''}{v''} = D$$

is the diameter of the circle of Fig. 6. This from 16 is very nearly

$$\frac{\omega^3 L_1 L_2 C_c^2}{C_2 R_2}$$

so that R_2 is obtained from the expression

$$R_2 = \frac{\omega^3 L_1 L_2 C_c^2}{C_2 D}$$

Applying this to the curve of Fig. 6, where $D = .94$, we have

$$R_2 = \frac{.5^3 \times 10^{18} \times 700 \times 10^{-6} \times 4{,}040 \times 10^{-6} \times 146^2 \times 10^{-24}}{865 \times .94}$$

$$= 9.3 \text{ ohms}$$

in close agreement with the value obtained by the straight line and circle construction.

This method can obviously be employed with any shape of coil, such as a toroid where the coupling by mutual inductance is not a simple matter, and it is rapid and fairly accurate.

(ii) The determination of frequencies can be made so precisely that measurements of capacities or inductances can quite readily be accurately made. For instance, if, after adjusting C_2 so that the voltmeter reading is at the middle of the wiggle, an unknown condenser is placed in parallel with C_2 and the value of C_2 altered until the voltmeter again indicates the middle of the wiggle, the difference between the two values of C_2 is the value of the unknown condenser.

BOOK REVIEW.

LES ONDES ELECTRIQUE COURTES. By René Mesny. Pp. 163, with 68 Figs. Les Presses Universitaires de France. 30 fr.

Professor Mesny is well known to all those who read current French wireless literature as one of the foremost workers and writers in the field of radio in France. He has been one of the most active pioneers in short-wave research, and this book from his pen may be confidently recommended to anyone desirous of obtaining an authoritative review of this latest branch of radio-telegraphy. It is not a popular book but a scientific review in which mathematical analysis is employed where necessary. The first of the three chapters deals with propagation and is subdivided into three sections entitled "Observed Facts," "Theories" and "Experiments and Criticisms." The second chapter on Emission and Reception is subdivided under the headings, "Generation of Short Waves," "Transmitting Aerials," and "Reception"; whilst the last chapter deals with laboratory experiments on short waves and measurements, and discusses the borderland between electrical and optical phenomena. A very useful feature of the book is a very complete bibliography giving references to 171 original publications.

ERRATA.

"SOME NEW COIL IMPEDANCE DIAGRAMS." page 89, col. 1, line 4. Left-hand member should be $1 + \omega^2 CL_0$. Line 12 shou'd read $\omega L_0 = -\frac{1}{\omega C_0}$

BOUND VOLUMES.

Past and Present: A Few Notes.

Presidential Address to the Radio Society of Great Britain, by Brig.-General Sir H. C. L. HOLDEN, K.C.B., F.R.S., M.I.E.E., delivered at the Institute of Electrical Engineers, on Wednesday, 26th January, 1927.

I AM afraid I cannot emulate my immediate predecessors in the Presidential Chair by discoursing on highly technical matters connected with Radio Communication, nor indeed on atoms and kindred subjects, although the greater part of my life has been spent in either designing, making or experimenting with weapons intended for reducing everything to atoms, which object they accomplished most successfully from this point of view in the Great War. Incidentally, however, the war did good in some directions, notably in the more rapid development of wireless apparatus and methods of communication than would have taken place in peace.

Labouring under the above disadvantages I have thought it might be of some interest to my hearers if I recall to their memory the early history of the Radio Society of Great Britain in the first place, and then make a few remarks on inventions and improvements which have been made mostly in the last fifteen years and have brought the science of communication by wireless to its present pitch of perfection. In conclusion I would like to say a few words regarding the present activities of the R.S.G.B. and what the Society aims at accomplishing in the near future.

The R.S.G.B., or its forerunner the London Wireless Club (later Society), has now been in existence for 13 years, the Club having been initiated in July, 1913, by Mr. René H. Klein, well known to wireless experimenters, with whom were associated Mr. McMichael and Mr. Fogarty. I refer to these gentlemen personally as I feel that all honour is due to them for their action and forethought at a time when the science was in its infancy, and experimenters were in need of the help and the combined strength that good organisation ensures.

I should like to remind you also that it was Mr. Hope-Jones, who became the first Chairman of the Society, who advocated its establishment on a less modest scale than was originally contemplated, when it was launched as the Wireless Society, a course that was followed and justified by its immediate success. All the men, professionally or otherwise prominent in wireless science, became in one way or another associated with the new venture and contributed to its growth and usefulness, and are still loyally supporting it—with the exception of a few pioneers who have passed away. I need not dwell any longer on the early history as full details are available in a most complete and interesting article which was published in the *Wireless World and Radio Review* of November 25th, 1922, and subsequently reprinted by the R.S.G.B. in pamphlet form.

I can only add that any member who has not read this will not regret taking an early opportunity of doing so. Incidentally the part taken by the R.S.G.B. in the initiation of broadcasting, as it is now generally known, is fully described.

I have often wondered what device, if any, will supersede the thermionic or triode valve as we know it to-day, seeing that it is undoubtedly the perfection of this appliance that has made extraordinary feats of telegraphy and telephony possible. I need hardly go into the early history of the two-electrode valve which rectified only, as this is so well known.

The triode valve came into practical use on a rapidly increasing scale during the Great War, and appears to have followed the De Forest "Audion," which, though it contained the same three elements, viz., filament cathode, grid, and plate anode, differed from the latter in its manner of operation, and also in its degree of exhaustion which was very much more complete.

The triode valve, under the name of the Pliotron (the meaning of which word is "amplifier"), was developed from a form of rectifying valve known as the Kenotron, in the research laboratories of the General

Electric Company of America by the addition of a fine wire mesh or grid for the purpose of controlling the current passing from the filament or cathode to the anode, and situated in the direct path between them.

This valve, as far as I know, was first described in an article written by Dr. Langmuir in the *General Electric Review* early in 1915, which was reprinted in the *English Electrical Review* in May, 1915.

The article in question is remarkable to my mind in that it contains such a store of information regarding the properties and action of this valve, and is eloquent testimony to the thorough manner in which the research which accompanied its development must have been carried out.

The best conditions necessary for the operation of the valve as a detector or as an amplifier, or again as an oscillator, are discussed at length, as well as the questions of grid bias and space charge—matters which have assumed increasing importance since then.

Full details are given of the elements of construction of the valves themselves and of experiments made with them in connection with H.F. transformers for radio frequency currents, as well as with L.F. iron-cored transformers for audio frequency currents. Typical illustrations are given of a radio receiving valve as well as of a valve destined for radio telephony purposes, and capable of controlling one kilowatt or more in the aerial.

The writer goes on to describe the method used to obtain a high tension direct current at 5,000 volts or more from the A.C. mains, or from an alternator smoothed by a condenser, rectified by a kenotron, and used to operate a pliotron oscillator the output of which is controlled by a small pliotron connected to the telephone transmitter. By this means the energy in the telephone transmitter circuit need be no greater than that in ordinary use.

He adds that it has been possible to connect up the radio telephone outfit with the regular telephone lines so that two subscribers can converse over their ordinary land lines when these are connected with their relative radio stations.

Since that time it is only in details of design construction and material that the valve has been improved, such as the substitution of the "dull" emitter filament, taking very much less current than the original "bright" one, and giving the necessary emission at a very much lower temperature and having the corresponding advantage of a much increased life. The principles of design, however, remain exactly the same.

I may be pardoned, I hope, for reminding you of what was done so long ago as 1914-15. My excuse for doing so is that it is an outstanding instance of the value of research which has thoroughly justified the expenditure of time and money in the far-reaching and important results produced.

A valve, which is practically three valves in one, has been produced in Germany within the last year, and it contains also the whole of the components and connections which comprise an ordinary three valve receiving set, minus of course the batteries. This valve, which is undoubtedly a real novelty, is reported to be something more than a freak and to act within its perhaps comparatively limited range of application, quite satisfactorily. It is not obtainable as yet in this country from radio dealers, and from inquiries I have made, the only sure and expeditious means of getting one is to go and fetch it yourself or get someone else to bring it from Germany, where there is no difficulty in purchasing them.*

The thermionic valve has other uses than for radio apparatus, and a comparatively new one is its employment in connection with the melting of precious metals in closed furnaces, especially for the melting and refining of platinum which I need hardly remind you requires a high temperature to reduce it to the fluid state, *viz.*, 1,780° Centigrade or its equivalent 3,236° Fahrenheit. This is not, however, to be regarded as the high limit of temperature which the high frequency furnace is capable of, as such is limited only by the infusibility of the material of which the furnace is constructed in practice.

The frequency employed is of the order of 300,000 cycles per second and the current is delivered to the water-cooled primary of a transformer surrounding the secondary

* Since I made this statement I have been told they can now be obtained through an agency in England.

which may be the mass of metal to be melted and from which it is separated by the wall of the furnace proper. The novelty in this of course consists in the use of high frequency currents instead of the low commercial periodicity ones which have been used in the induction furnaces for melting steel, etc., for many years.

A more interesting use to us is to be seen in its application to valve manufacture, where it is used for raising the interior portions of valves to a high temperature in order to release occluded gases whilst they are being exhausted, it having been found that heating them by the action of high frequency currents, apart from other practical advantages, from the point of view of more complete evacuation, is more effective than by the application of some source of heat to the exterior, overheating the filament, etc., the older method.

It appears likely that the use of the high frequency current type of furnace may find further applications in the future, and it is not unlikely that unless steps are taken to prevent it such a furnace would affect radio receiving apparatus which happened to be installed in its neighbourhood.

For this reason, if for no other, the high frequency current furnace may be of interest to my audience.

One of the most important subjects at the present time that is attracting the attention of the whole of the wireless experimental world, of which the members of the T. and R. section are a far from negligible part, is the short-wave one.

I have so far been unable to find any definite pronouncement of an authoritative character as to what is meant by a short wave, *i.e.*, the limits of its length. Captain Miles, in his lecture on this subject before the Society, in November, 1925, defined them, for his purpose at any rate, as those below 100 metres, but as far as I can judge others might put this figure at 200 or 300, or even more.

Anyhow, surely it would be a convenience if a conventional maximum limit for the short wave range were laid down.

Whether this range is expressed in metres, radio wavelength, or in frequency per second is immaterial compared to the question of the maximum limit.

The amateur, or, as I should prefer to term him, the radio experimenter, had a slice of luck when he was told years ago that he must confine his activities to wavelengths below 200 metres. It was not long before he discovered that the gift which he had despised was just what he had wanted, though he was unaware of it.

Although the success of the short wave long distance transmission is an accomplished fact, there are many phenomena connected with it the explanations of which are as yet conjectural, or perhaps I should say the reasons for which are not yet satisfactorily accounted for.

The Kennelly-Heaviside ionised layer in the atmosphere has much responsibility thrust upon it. Its height is constantly varying and this it would appear affects the distance covered by the " skip," but not the angle of incidence with the layer or departure from it. For the signals to reach the same point as before when the height of the Heaviside layer has been much altered, from midday to midnight, for example, it appears to be necessary for the transmission wavelength to be modified. Are the assumptions generally made, and the explanations given to account for these phenomena, correct? Again, one might expect that some form of the " beam " system would give as good, if not better, results than any based upon the relationship of the aerial and wavelengths for a given angle of departure. I believe that the noted authority, Dr. Alexanderson, has been carrying out experiments in America with a beam system on some such lines, but I have not heard what results he has obtained.

One point, however, stands out very clearly in any controversy respecting the merits of the long wave *versus* the short wave system, and that is the enormous disproportion between the energy required to obtain a long range result even where the conditions are most favourable to the long wave, and that required for good communication on a short wave.

Clearly there is much more experimental and research work to be done to explain the idiosyncrasies of the short-wave system by itself, and perhaps combined with the beam, which appears to offer great possibilities.

There is sometimes a tendency to feel disheartened because one's experimental equipment is meagre compared to that of research

laboratories, etc., but this feeling should be counteracted by the fact that some of the most epoch-making discoveries and inventions have been made by men with apparatus of the simplest character. Outstanding instances in the electrical world are Professor Graham Bell, the inventor of the telephone, and Professor Hughes, the inventor of the microphone.

There is another and kindred matter I should like to make a brief allusion to, as it is of special interest to a number of our members. It is the automatic and accurate control of wave frequency.

This is such an important problem that I make no apology for referring to it, and indeed with the rapidly increasing number of transmitting stations, Government, broadcasting, and private experimenters', it is obvious that its importance must tend to increase if interference is to be minimised.

It naturally also affects the receiver according to the degree of selectivity of the apparatus in use. Three methods of control are employed at the present time, having as their basis :—

(*a*) The well-known oscillatory circuit tuned to the frequency required.

(*b*) The tuning fork maintained electrically, the frequency being obtained from one of its higher harmonics.

(*c*) The quartz crystal slab used as an oscillator.

Of these the only one that can be said to fulfil the following conditions which are most desirable, more especially to the experimenter with short waves, is the quartz crystal. These conditions are :—

(*d*) Simplicity owing to its rate being controlled by its actual dimensions.

(*e*) Constant frequency, owing to its rate not being affected by electrical variations in the circuit, small variations of temperature, etc.

(*f*) That it is practicable to make it of such dimensions that its fundamental will correspond with a wavelength as short as 45 metres.

That a quartz crystal has a natural period of vibration governed by its dimensions has been known for many years, but it is only comparatively recently that this property has been harnessed to do work for radio transmission.

Several of the members of the R.S.G.B. are fully alive to the properties and advantages, and one of them, Mr. Hinderlich, recently read a paper before the Society explaining how the crystals could be made, and giving other invaluable information as to their mounting and use.

Quartz crystal control has for some time past been employed for controlling the frequency of various broadcasting stations abroad and appears to be on the increase. It has not yet come into use for broadcasting in this country.

I understand that other materials besides quartz are found to possess similar properties though in a less degree—it would seem, therefore, that there might be a field for useful research in this direction. Such work, though it may turn out fruitless in the direction contemplated, not infrequently leads to unsuspected discoveries being made in other directions, and this fact may prove a partial incentive in undertaking it.

It is curious to note in contrast with the great and rapid progress of improvement in the apparatus used in radio communications, including receivers for broadcasting, how little the telephone, invented by Professor Graham Bell, has been improved or even materially modified.

I will recall to your minds the fact that, in its early form as first exhibited in England by the late Sir William Preece at the meeting of the British Association at Plymouth in August, 1877, it had a bar magnet with a polar extension of soft iron at one end, carrying a bobbin wound with the usual insulated copper wire, mounted centrally as regards the diaphragm of thin iron sheet (ferrotype used for photographic purposes). The wooden case formed the handle and the general arrangement was similar to the ordinary telephone exchange receiver in universal use to-day. There have been innumerable modifications, mainly of form, made between that date and the present time, the bipolar form of magnet with its two coils having taken the place of the single one, but it is nevertheless the fact that probably the best and certainly the most sensitive phone receiver to-day has its magnetic movement connected to the centre of the diaphragm which produces the sound waves, and the latest forms of loud-speakers which are claimed to produce the most

natural results are somewhat similarly constructed.

The fact that after all these years only comparatively trifling modifications of the original instrument have been made is silent testimony to the inventive genius of Prof. Graham Bell.

On the occasion of the meeting alluded to the lecturer used the following words: "It is quite evident, however, that Bell's telephone is limited in its range." This statement, though perfectly accurate at the time and under the conditions then existing, would be truer now if the word "unlimited" were substituted for "limited" in view of the Transatlantic telephone service so recently inaugurated, and which, without the telephone, could not even have been conceived.

At the present time a good deal of attention is being paid to the matter of rectifiers for rectifying low frequency currents from electric supply companies' mains, either for charging accumulators for filament heating or for the higher voltages required for plate current, and alternatively for supplying both these requirements direct. The demand for rectifiers has arisen, I think, owing to the increased use of power valves for loudspeakers, which are designed to control much greater amperage than was usual a short time ago, when dry batteries were able to do all that was then required of them. There is still a field open to inventors to produce a perfect rectification device within the reach of those whose purses are somewhat slender.

Rectification of an alternating supply can be made by (1) mechanical means such as a motor generator or vibrating rectifier; (2) electrolytic means—for instance, tantalum or aluminium rectifying cells; (3) thermionic rectifying valves of one sort or another.

All these methods have disadvantages of one sort or another: (1) is costly, especially if arranged to supply both filament and H.T. current; (2) necessitates the use of cells and undesirable acid or alkaline solutions, and so far as the aluminium rectifier is concerned a good deal of attention to maintain it in running order; (3) is free from the disadvantages of (2) but entails a large drop in voltage, and when an ordinary valve is used arrangements have to be provided to heat the filament. If a mercury rectifier is used this requires also an additional device for putting it in action.

Although it is not suggested that the above are ineffective for their purpose, it is evident that there is a need for some rectifier which is free from all such disadvantages. A new departure in low frequency rectifiers was described and exhibited at a meeting of the American Physical Society in September last which would appear to have much in its favour if it is lastingly effective in its action. It was stated that the instrument, the size of a watch, say about $1\frac{1}{2}$ in. in diameter, would rectify a current of 3 amps with a drop of only $1\frac{1}{2}$ volts across its terminals. This rectifier consists of two discs of metal, one of copper and the other of lead, clamped together under considerable pressure. The face of the copper disc is covered with a layer of oxide of copper, stated to be produced by prolonged heating in air. If this rectifier comes up to expectations in actual practice it will prove of considerable value.

Probably there are other combinations that would act equally well, and this might be a fruitful field for research by an experimenter, and one which with a comparatively small expenditure might bring him in a rich harvest. It is in any case obvious that a simple device of the sort described could find many useful applications apart from radio ones.

Speaking quite generally, the conditions under which rectifying of an alternating current, either partial or complete, other than by mechanical means, takes place is not too well understood, and any contribution to existing knowledge, either from the theoretical or practical standpoint, would be welcome.

For radio purposes, after rectification some smoothing device is always necessary, and in most cases transformers have to be used to supply the right voltage, and in addition to this to have a centre tap in order to deal with the whole wave.

Early in 1925, and mainly at the instigation of the Society, a move was made by manufacturers and others in the matter of standardisation of radio components, and the essential qualities of which they ought to be made, as it was felt that the time had arrived when not only the members of the

R.S.G.B., but also the users and makers of wireless apparatus generally, would be greatly benefited if they had some reasonable assurance as regards the reliability of insulating material, used for panels for radio instruments, such as ebonite that they might wish to purchase, and also the inter-changeability of components such as plug-in coils, to quote another example, and the limits of accuracy of fixed condensers.

The British Engineering Standards Association was approached and, having been readily satisfied of the necessity for and the advantages which would accrue to manufacturers and users alike if such standardisation was effected, set up the necessary Committee to carry the scheme into effect.

The first specification was published in November, 1925, and is entitled "British Standard Specification for Ebonite for Panels for Radio Reception Purposes," and numbered No. 234/1925. The specification lays down tests for quality of material which have to be complied with, as well as the dimensions recommended for panels and strips.

As has been the case in other industries, the idea of standardisation was not at first received with any marked enthusiasm by the majority of the manufacturers who, though often in favour of standardisation in principle, for one reason or another seem to find a difficulty in its application to their own products.

I am glad to say that this feeling and attitude seems to be gradually passing away. In the case of the standard ebonite I see that some of the well-known manufacturers are now offering material marked with the BESA mark, thereby guaranteeing that it complies with the specification.

Another specification for "Fixed Condensers for Radio Reception Purposes," No. 271/1926, has been recently published. Further work is in hand dealing with plug-in coils, and a specification for these will no doubt be issued before long.

It may seem to the casual observer that standardisation is quite a simple matter, but this in reality is not so, as it is only possible in practice to standardise such characteristics of parts and such dimensions as will not fetter nor interfere with design. The standardisation of even such a simple device, one would think, as the pin and socket of a plug-in coil raises all sorts of unforeseen difficulties, although when accomplished everyone expresses astonishment that it was not done long ago.

I think I have said enough to show that the Council of the Society is fully alive to the furtherance of the interests of the members, and is not afraid of undertaking pioneer work on their behalf. I feel confident too that I shall not be a false prophet if I prophesy that the standardisation of radio parts will be much appreciated by all parties in the days to come.

I myself attach some importance to the matter of standardisation and hope that our members will assist the movement in any way that they can by demanding and using, when they are able to, such products as are guaranteed to comply with the BESA specifications.

Another of the Society's enterprises, started in the latter part of last year, is being carried on in co-operation with the Wireless League. I refer of course to the Joint Scheme of Registration of Wireless Traders and Repairers under which it is hoped that purchasers and users of wireless apparatus may be guided as to which firms they may deal with with confidence as to quality of goods supplied and also be guided as to capabilities for effecting repairs in a proper manner.

Applicants for registration under one or both of the above categories are required to give full information, treated confidentially, of course, to the Joint Committee of the above two bodies, of their premises, resources, technical qualifications, etc. These are all examined and verified by personal inspection, and when necessary supporting evidence is called for from disinterested parties.

On the information thus obtained the Joint Committee decides whether the certificate, which is in effect also one of competence and fair dealing, shall be issued to the applicant or not. When a certificate is issued a plaque of conspicuous design is sent to be exhibited outside the premises.

Considerable support has already been accorded by traders to this scheme, and I feel confident that as the scheme becomes better known it will be appreciated by, and benefit both, the retailer and his customers.

Quite recently, last month in fact, the British Broadcasting Corporation has invited

the R.S.G.B., the Wireless League, and two other associations to form a Committee which will hold its meetings at their offices in Savoy Hill, and will consider such questions, technical and otherwise, as may be brought before it by the above representative bodies.

In the evidence given for the R.S.G.B. before the Broadcasting Committee in January, 1926, it was pointed out that a closer touch between the R.S.G.B. and the B.B.C. was considered would be an advantage to both bodies, and we therefore welcome the formation of this Committee, and the Council has nominated two members to sit on it.

It is not out of place to remind you that our relations with the Government Departments are, as they always have been, amicable. The R.S.G.B. is duly recognised by the Postmaster-General and his officials, who are always ready to give us a hearing and consider our representations on subjects which come within his province.

As regards the future, there is plenty of scope for the R.S.G.B. as such, and for its individual members to continue the useful work they have done in the past for the furtherance of the science we have all so much at heart.

This particularly applies to the members of the Transmitter and Relay Section who were pioneers in the accomplishment on the short wavelength of communication by wireless with the Antipodes. There are several men whom we especially honour for their achievements, but they, as well as others, appreciate fully how many problems still remain to be solved, and how much remains to be done, in spite of the very rapid progress that has been made in the last year or so in almost every direction.

The Purpose and Design of Broadcast Receivers.

Informal Discussion at I.E.E. Wireless Section.

THE February meeting of the Wireless Section I.E.E., held on 2nd February, was devoted to an informal discussion on "The Purpose and Design of Broadcast Receivers."

In opening the meeting, Mr. E. H. Shaughnessy (who presided in the absence of the Section Chairman, Prof. C. L. Fortescue), made reference to the award of the Hughes Medal of the Royal Society to Admiral of the Fleet Sir Henry Jackson, and conveyed the congratulations of the meeting on this honour.

The discussion was opened by **Mr. C. F. Phillips** who said that the subject might seem hackneyed but was nevertheless a matter of general interest. The purpose of the receiver should be to bring home the fare provided by the B.B.C., and reproduce it with good quality and intensity. The price should be reasonable and maintenance easy. The reception of one or two stations was easy, but distant stations were frequently attractive. Was it possible to manufacture commercially a long range broadcasting receiver of good quality, easy of control and of reasonable price?

He then discussed briefly the straight radio-frequency set *versus* frequency changing (*i.e.*, supersonic heterodyne). With neutralising and shielding two-thirds or three-quarters of the valve μ could be realised on straight sets. Radio frequency stages were usually limited to two or three giving overall amplification of 1,000 to 1,500. Supersonic seemed simpler. With the lower frequency of the intermediate stages it was possible to utilise nine-tenths of the valve μ per stage, and 8,000 to 9,000 could be obtained. High quality was possible if the second detector was not overloaded and this was usually more serious than loss of quality by cutting the sidebands.

Broadcast sets now needed a definite rating, which could best be done in terms of power. He suggested specification of the D.C. power supplied to the last valve, and quoted 4 watts as a maximum

necessary. With a valve of μ 3 and 3,000 ohms impedance, 4 watts—*i.e.*, 20mA at 200 volts—with 30-35 volts grid-bias allowed a swing of 160 volts in the last valve. This would represent 0.6 volt-amp in the loud-speaker and this volume was sufficient for a large room. As a minimum he suggested 1.2 watts, *i.e.*, 10mA at 120 volts, with 16 volts grid-bias. The reproduction was not so good but was ample for a small room.

It was, therefore, desirable to design for an input of 4 watts to the last valve and work backwards. The preceding stage could then give about 45, with 10 from the detector to the penultimate valve.

Dealing with rectification, the grid method was most sensitive but opinion was divided as to distortion. Rectification was better at the lower modulating frequencies, which was probably an advantage as the amplification fell off at lower frequencies while the loud-speaker was also less efficient. Grid rectification did damp the H.F. coupling circuits. With anode bend rectification, sensitivity was inferior but selectivity was better. Frequency distortion was absent, although wave form distortion was present. This method also called for more skill and additional control. Special methods of rectification were also known including those of Capt. Round, and of the B.B.C., referred to by Mr. Denman in his description (*Wireless World* of 26th January, 1927) of the apparatus at the Science Museum, South Kensington.

Resistance-capacity coupling was becoming popular, but design was full of pitfalls. With a well-designed transformer and valve it was easy to build an audio-frequency amplifier. With resistance-capacity frequency distortion should be absent, but only if stages were well designed. A time-constant of $\frac{1}{40}$ second was feasible with a coupling condenser of 0.1μF and $\frac{1}{4}$ meg-ohm grid-leak. The usual equation did not hold as the coupling condenser and grid-leak and valve capacity were in parallel with the anode circuit. The anode resistance was a matter of some design. The higher the resistance the lower the anode volts. With a valve of μ=20, a resistance of 50,000 ohms was suitable. The recent ultra-high resistance was impracticable at the higher frequencies as the next valve shunted the anode reactance, and caused a fall of amplification at the higher frequencies.

Finally as regards the valve it was important to have a low impedance. The loud-speaker was in the same position in regard to this valve as the L.F. transformer primary in the previous stage. Its impedance should be greater than that of the valve. In using a transformer or choke for output the problem in a commercial set was serious. With 20mA in the last stage, the iron would have to weigh 2-4 lbs.

The ideal receiver design should be capable of operating on comparatively strong signals. The power and position of transmitting stations should be arranged for alternative programmes. There should not be more than one radio-frequency valve before the detector, and it should be not so much for amplification as for selectivity.

Mr. L. C. Pocock, who continued the discussion, did not think 4 watts excessive but very reasonable. The B.B.C. should supply alternative programmes and it would probably be found that demand for two close stations would be the aim of the sane majority of the public in the near future. He discussed selectivity and comparative distortion with superheterodyne and three radio-frequency valves, and the difficulty of using a highly selective set. The supersonic was good in this respect. As regards power valves, four or five watts were quite reasonable, and valve cost was not great compared with first cost. The L.F. amplifier and transformer were not yet fully exploited. It was possible to get a transformer good enough for any loud-speaker available. As regards the loud-speaker there was need for attention to design on known points.

Mr. P. W. Willans expressed agreement with the advantages of the supersonic heterodyne. It could be made reasonably cheaply and compact. A change of range was difficult on a multistage straight set. The object of design should be to take the fullest advantage of the high μ of the valves. A mixed amplifier was a good thing as regards sensitivity. With high μ valves one H.F. stage, two at intermediate frequency and one L.F. stage for the loud-speaker should be sufficient. In connection with the comparison of resistance and transformer

couplings the use of a transformer was of advantage in getting rid of the higher frequency; as for example, getting rid of the intermediate frequency at the second detector of a supersonic set.

Mr. H. Bevan Swift queried what happens when receivers are in the users' hands. Change of valves, voltages, etc., might give quite different behaviour from that intended by the maker. He also discussed transformer coupling and flux density, pointing out that in practice the density was actually very small.

Mr. P. K. Turner said that the flux density was greater than suggested since the iron was subjected to the D.C. magnetisation. With a good transformer of about 6,000 primary turns with 3mA D.C., the flux density would be 3,000 to 4,000 lines. He did not think high power sets were at present feasible for really good quality. With a set having two valves and three transformers, at 6,000 metres an amplification of 10,000 was obtainable but only 2,000 could be used on account of the cut-off of the sidebands. In order to use six or eight stages it might be necessary to employ couplings of band pass filters. Information was necessary as to phase throughout the amplifier. Much of the music was actually in the form of transients.

Mr. B. S. Cohen discussed rectifiers, stating that a straight-line rectifier had been devised, and a four-electrode valve circuit had been used in this respect with success. The transformer had been suggested as a frequency limiter. Why not make more use of filters?

Mr. Willans pointed out that the leakage inductance did act as a choke or filter.

Mr. Carpenter briefly commented on the comparison of anode bend and grid rectification.

Mr. McPherson referred to selectivity by directional aerials. Should not more attention be paid to this? With a near station it was also useful as a volume control. With reference to overloading at the second detector of a superheterodyne, overloading could take place at any detector and called for attention. The efficiency of bottom bend was greater with large inputs. For the output transformer stage he would suggest the use of the push-pull system.

Col. H. Lefroy discussed the impedance of the loud-speaker and its relation to the anode impedance.

Mr. Morris dealt with oscillation. It was necessary for designers to standardise with a view to eliminating this trouble. Another speaker pointed out that any amateur with simple components could produce oscillation. This was a matter with which the manufacturer could not deal.

Mr. Dew asked for information of the time constant of resistance-capacity circuits, and of the loud-speaker as a radiator.

Mr. R. P. G. Denman thought that a market for high quality sets would grow. For good quality 4 watts was not high—he actually used 30. The straight-line rectifier referred to was very good, but he had been unable to detect any change on switching from it to a bottom bend rectifier.

Mr. W. A. Erlebach discussed the design of power transformers. Radio transformers were not different except for the super position of the D.C. He agreed that the flux density was low and that bulk of iron would make only little difference in quality.

Mr. C. F. Phillips concluded and summed up the discussion, replying briefly to several of the points raised by the other speakers.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 86 *of February issue.*)

9. (A) Series.

THE word "series" has essentially the same meaning in mathematics as in ordinary speech, and when a series of misfortunes is described as "one confounded thing after another" the same idea of an ordered succession of separate things is involved. Any ordered succession of numbers

$$a_1, a_2, a_3, a_4, a_5, \ldots . a_n$$

is called a series, but a quite random succession, such as

$$18, 1, 5\tfrac{1}{2}, 7\tfrac{3}{8}, 5003, \text{etc., etc.,}$$

is not of any practical interest. It is form without significance, and these numbers might have been arranged by a trained monkey or a gust of wind. But in the matter of series, as in everything else, any sign of law or design gives significance to the form and the mind becomes interested. For instance,

$$0/1, 2/3, 4/5, 6/7, \text{etc., etc.,}$$

shows evidence of thought, and nothing less than human could have arranged this series. It is designed according to a definite plan and can be related to the simplest series of all, that of the cardinal numbers, by means of a general formula which expresses this law and summarises the design. The law can be put in the form

$$a_n = \frac{2n-2}{2n-1}$$

a_n being the nth term. The first term is obtained by putting $n=1$, *i.e.*, 0/1, the second by putting $n=2$, *i.e.*, 2/3, and so on. An ordered series of this kind really grows out of the idea of a function, for the general or nth term is a function of n, *i.e.*,

$$a_n = f(n)$$

where the argument n takes in succession the values 1, 2, 3, etc. Moreover, the function need not contain n and numbers only. It may contain one or more letter symbols as well. For instance,

$$1, 2x, 3x^2, 4x^3, \ldots . nx^{n-1}$$

is a series the terms of which are functions of x and of n. Thus an infinite variety of form is included in the general idea of a series, and the series form of representation plays a very large part in theoretical and applied mathematics.

(B) *The Sum of a Series.*

Next to the form or law of a series, the most important thing to know about it is its sum, *i.e.*, the sum of its terms. Think of a number, for instance, say, 21493. This is the sum of a series, a series of powers of ten, for it is only a short way of writing

$$2\times10^4+1\times10^3+4\times10^2+9\times10^1+3\times10^0$$

Again 3.1415 is a short way of writing

$$3^4\times10^0+1\times10^{-1}+4\times10^{-2}+1\times10^{-3}+5\times10^{-4}$$

a series which symbolises the fundamental process of approximation. This illustrates the basic character of the summation of a series which we must now consider.

First we will take the simple case in which there is a limited, *i.e.*, finite, number of terms. The sum of such a series is of course just what the phrase implies, *i.e.*, the number which results from the adding together of all the terms of the series, but in this connection the word sum is usually given a rather special sense, and finding the sum of the series means finding some general formula which provides a shorter way of arriving at the result than by the detailed addition of the separate terms. Take for instance a simple "arithmetical progression" as it is called, in which each term differs from the preceding one by a constant number, *e.g.*, 3, 7, 11, 15, etc., or, in general terms, a, $a+d$,

$a+2d,\ a+3d, \ldots\ a+(n-1)d$. The sum of n terms is

$$S_n=a+(a+d)+(a+2d)+(a+3d) \ldots \{a+(n-2)d\}+\{a+(n-1)d\}.$$

In this case a short formula can be found for the sum by means of a trick. Turning round the right-hand side,

$$S_n=\{a+(n-1)d\}+\{a+(n-2)d\} + \ldots (a+d)+a$$

and adding these two equations term by term gives

$$2S_n=\{2a+(n-1)d\}+\{2a+(n-1)d\} +\{2a+(n-1)d\}, \text{ etc., } \ldots \text{ n terms in all.}$$
$$=n\{2a+(n-1)d\}$$

so that

$$S_n=\frac{n}{2}\{2a+(n-1)d\}=n(a+l)$$

where $l=a+(n-1)d$

i.e., l is the last term.

Again, for another simple form, the so-called geometric series in which each term bears a constant ratio to the preceding term, *e.g.*, $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, etc., or in general terms, a, ar, ar^2, ar^3, etc., ... ar^{n-1}, the sum of n terms is

$$S_n=a+ar+ar^2+ar^3+ar^4, \text{ etc., } \ldots ar^{n-1}.$$

Therefore

$$rS_n=ar+ar^2+ar^3+ar^4, \text{ etc., } \ldots ar^{n-1}+ar^n,$$

and by subtraction,

$$S_n(r-1)=ar^n-a=a(r^n-1).$$

Therefore $$S_n=\frac{a(r^n-1)}{r-1}$$

For instance, the sum of 32 terms of the series $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, etc., would be

$$S_{32}=\frac{\frac{1}{4}(2^{32}-1)}{(2-1)}$$
$$=2^{30}-\frac{1}{4}$$

This commemorates the tragic fate of the desperate fugitive who offered a blacksmith a farthing for the first, a halfpenny for the second, a penny for the third, and so on, for the 32 nails of the four shoes of his horse. The bill came to just under four and a-half million pounds.

In addition to the above two simple standard series, the arithmetic* and the geometric, there are various other types which can be summed by means of general formulæ, but these are not of much practical importance, so we will proceed at once to the much more general propositions relating to the sum of an infinite number of terms of a series.

(c) *The Sum to Infinity. Convergency and Divergency.*

First, what is meant by an infinite series? Given a general term

$$a_n=f(n)$$

say,

$$a_n=\frac{1}{2^{n-1}}$$

for instance, then if there is no upper limit specified for n the number of terms can exceed any finite number, however large, *i.e.*, can be infinite. What, then, is the sum to infinity? It cannot mean the result of adding the terms together, for that is an unending process. It is conceivable, however, that S_n may have a finite limit when n is increased indefinitely, *i.e.*, it may be possible to find a quantity S such that by making n sufficiently large, S_n can be made to approximate to S within any standard, however small. The quantity S is then called the sum to infinity of the series. Actually it is the limit of S_n when n tends to infinity, *i.e.*,

$$S=\underset{n\to\infty}{lt.}\ S_n$$

This limit S will never be reached by the sum of any finite number of terms, but it can be approached to any desired standard of accuracy by taking a sufficiently large number of terms. Take, for example, the series quoted above for which

$$a_n=\frac{1}{2^{n-1}}$$

This is a geometric series of which the first term, a, is 1, and the common ratio r, $\frac{1}{2}$. From the formula given above

$$S_n=\frac{1\times(1-\frac{1}{2}^n)}{(1-\frac{1}{2})}=2(1-\tfrac{1}{2}^n)$$

Now by making n sufficiently large, $(1-\frac{1}{2}^n)$ can be made to differ from 1 by as little as we please, *i.e.*, it can be made to approximate to 1 within any standard, so that

$$S=\underset{n\to\infty}{lt.}\ S_n=\underset{n\to\infty}{lt.}\ 2(1-\tfrac{1}{2}^n)=2$$

* Pronounced with the accent on "met."

In general, for the geometric series

$$S_n = \frac{a(1 - r^n)}{1 - r}$$

and provided r is less than 1 numerically the limit of $1-r^n$ when r tends to infinity is 1, and

$$S = \underset{n\to\infty}{lt.} S_n = \underset{n\to\infty}{lt.} \frac{a(1 - r^n)}{1 - r}$$
$$= \frac{a}{1 - r}$$

It should already be clear that not all series will have a finite sum to infinity. In the above case, for instance, if r is equal to or greater than 1

$$S_n = \frac{a(1 - r^n)}{1 - r} = \frac{a(r^n - 1)}{r - 1}$$

will increase without limit as n tends to infinity. In fact, series can be divided into two classes—those which have and those which have not a finite limit for the sum to infinity. Series of the first kind are called convergent, and play a very large part in applied mathematics. The others are called divergent, and are not of much use to anyone. (Note: A series will be called divergent unless S_n tends to a finite limit as n tends to infinity, in accordance with the definition of limit; but it does not follow that S_n will increase without limit for all divergent series. For instance, the series $a, -a, a, -a$, etc., which is a geometric series having a as the first term and -1 as the common ratio, gives $S_n = 0$ or $-a$ according as n is even or odd, however large n may be. This kind of divergent series is called "oscillating.")

It is clear that the important thing to know about an infinite series is whether or no it is convergent. If it is, then although it may not be possible to find any simple expression for the limit of the sum to infinity, as close an approximation to it as may be desired can be found by actually calculating and adding together a sufficiently large number of terms, whereas if the series is divergent, this would be a vain pursuit of something which does not exist. Where a series is a function of n and of some other independent variable x, for instance,

$$1, x, x^2, x^3, x^4, \text{etc., etc.} \ldots x^{n-1}$$

the sum to infinity may be finite for a certain interval of values of x and infinite or oscillating for others. In fact, we have already shown that this series is convergent for all values of x between plus and minus 1 and divergent for all other values of x. In any case of this kind it will be necessary to know for what interval or intervals of values of the argument the series is convergent.

For these reasons a great deal of research has been directed to the discovering of tests for convergence, tests which can be applied to a series as a preliminary operation, to find out whether and under what conditions a sum to infinity actually exists. The research has so far failed to establish any single test of universal application which separates the sheep from the goats; but a considerable number of tests of very useful even though limited applicability have been developed. A few of the most useful of these will now be described, but for a full account of this rather difficult and voluminous subject some standard text-book, such as *Chrystal's Algebra*, should be consulted.

(D) *Tests for Convergency.*

The series will be represented by

$$a_1, a_2, a_3, a_4, \text{etc., etc.,} \ldots \ldots a_n,$$

a_n being the nth term. Two perfectly general points should be noted first. The sum of any finite number of terms is finite. Therefore if a series can pass a test for convergence for all terms after a certain point, say the rth term, then it is convergent, even though the terms up to this point do not satisfy the convergency condition. Again, if a given series of positive terms is convergent, any series differing from it only in the sign of some of the terms will also necessarily be convergent.

A first minimum test of convergence is that

$$\underset{n\to\infty}{lt.}\, a_n = 0$$

for a series is not convergent unless S_n, S_{n+1}, S_{n+2}, etc., converge to a finite limit S, so that S_n, S_{n+1}, S_{n+2}, etc., differ from S, and therefore from each other by a quantity which can be diminished without limit by making n sufficiently large. Therefore

$$\underset{n\to\infty}{lt.}\, (S_{n+1} - S_n) = \underset{n\to\infty}{lt.}\, a_{n+1} = 0$$

(Note that $\underset{n\to\infty}{lt.}\, a_{n+1}$ is the same as $\underset{n\to\infty}{lt.}\, a_n$.)

A series of which this is not true cannot

be convergent. Unfortunately, very unfortunately in fact, it does not follow that a series is convergent if $\underset{n\to\infty}{lt.}\, a_n = 0$.

For instance, the series

$$\frac{1}{1}, \frac{1}{2}, \frac{1}{3}, \frac{1}{4} \ldots \ldots \frac{1}{n}$$

fulfils the condition, but it can be shown that this series is divergent. The condition is therefore a minimum but not a sufficient one. It is nevertheless a useful point to remember, and will sometimes save further investigation.

A series is convergent if the ratio of each term to the preceding one is numerically less than unity; for

$$a_1 + a_2 + a_3 + a_4 + a_5 \ldots + a_n \ldots$$

etc., etc., *ad. inf.*, can be written in the form

$$a_1 \left\{ 1 + \frac{a_2}{a_1} + \frac{a_3 a_2}{a_2 a_1} + \frac{a_4 a_3 a_2}{a_3 a_2 a_1} + \frac{a_5 a_4 a_3 a_2}{a_4 a_3 a_2 a_1} \ldots \text{ etc., etc., } ad.\ inf. \right\}$$

Now by hypothesis

$$\frac{a_2}{a_1} < r$$

$$\frac{a_3}{a_2} < r$$

etc., etc., where $r < 1$. Therefore the sum of the series is less than

$$a_1(1+r+r^2+r^3+r^4 \ldots \text{etc., etc., } ad.\ inf.)$$

But

$$1+r+r^2+r^3+r^4 \ldots \text{etc., etc., } ad.\ inf. = 1/(1-r)$$

since r is less than 1. The sum of the series is therefore less than $a/(1-r)$ and is therefore convergent.

Notice that this proof will break down unless

$$\frac{a_{n+1}}{a_n} < 1 \text{ numerically}$$

however large n may be. The series will therefore not be convergent unless

$$\underset{n\to\infty}{lt.}\, \frac{a_{n+1}}{a_n} < 1 \text{ numerically.}$$

Conversely, if the above condition is fulfilled the series is convergent; for let

$$\underset{n\to\infty}{lt.}\, \frac{a_{n+1}}{a_n} < r \text{ where } r < 1$$

Then, by definition, if m is made large enough

$$\frac{a_{m+1}}{a_m} \sim r < \epsilon$$

however small ϵ may be, and if ϵ is made small enough

$$r + \epsilon < 1$$

since $r < 1$

If, therefore,

$$\underset{n\leftarrow\infty}{lt.}\, \frac{a_{m+1}}{a_n} < r$$

where $r<1$, we can find some fixed term, say the mth, from and after which a_{m+1}/a_m is less than 1. The series will therefore be convergent as already shown.

In addition to the above, there are two comparison theorems which are of use. Given two series

$$a_1, a_2, a_3, a_4, a_5 \ldots a_n \ldots \text{etc., etc., } ad.\ inf.$$

and

$$b_1, b_2, b_3, b_4, b_5, \ldots b_n \ldots \text{etc., etc., } ad.\ inf.$$

of positive terms, then if the a series is convergent and each term of the b series is less than the corresponding term of the a series, the b series will also be convergent. This is sufficiently obvious without any formal proof.

Another comparison, not so obvious, is this. If the ratio of corresponding terms is always finite the series will be either both convergent or both divergent. Suppose the a series to be convergent, its sum to infinity being S_a, and let k be the largest value of the ratio b_n/a_n of any two corresponding terms. Then the sum of the b series is less than kS_a, and the b series is therefore convergent. If, on the other hand, the a series is divergent, its sum to infinity being infinite and r is the smallest value of the ratio of two corresponding terms b_n/a_n, the sum of the b series is greater than r times the sum of the a series and, the b series is therefore divergent.

A useful test series to which the above theorems can be applied is

$$\frac{1}{1}, \frac{1}{2^k}, \frac{1}{3^k}, \frac{1}{4^k}, \frac{1}{5^k} \ldots \ldots \ldots \text{ etc., etc., } ad.\ inf.$$

which can be shown to be convergent if k is numerically greater than 1, and divergent if k is equal to or numerically less than 1.

All the above tests of convergence have been stated in relation to series of positive terms, but in view of the general statement

made above about series of which the terms vary in sign, there should be no difficulty in applying them to such series. It should be pointed out, however, there are series which are divergent if all the terms are positive but convergent if they are alternatively positive and negative. In fact it can easily be shown that a series having alternately positive and negative terms is convergent if each term is less than the preceding, and if the terms decrease without limit in absolute magnitude.

(E) *Some Important Series.*

One of the most useful series in the whole of mathematics is

$$1,\ mx,\ \frac{m(m-1)}{1.2}x^2,\ \frac{m(m-1)(m-2)}{1.2.3}x^2,\ \text{etc., etc.}$$

This, for a reason which will appear later, is called the Binomial Series. The general or nth term is

$$a_n=\frac{m(m-1)(m-2)(m-3)\ldots(m-n+2)}{1.2.3.4\ \ldots\ (n-1)}x^{n-1}$$

and the $(n+1)$th term is therefore

$$a_{n+1}=\frac{m(m-1)(m-2)(m-3)\ldots(m-n+1)}{1.2.3.4\ \ldots\ n}x^n$$

This, by the way, introduces a new notation. The denominator in a_{n+1} is the product of all the whole numbers from 1 to n. This is a group which very frequently occurs in mathematics, especially in series. It is written for shortness $\underline{|n}$, and is called "factorial n." There is an alternative and more recent notation in which it is written $n!$ This has the advantage that it is all on one line. It is still called "factorial n" in this form, though one of the brighter sort of mathematicians always refers to it as "n By Jove!" The name has not been adopted in teaching circles because it is liable to disturb a class.

Returning to our series the first thing to notice is that if m is any positive whole number the series terminates at the $(m+1)$th term, because the $(m+2)$th term contains the factor

$$m-(m+2)+2=0$$

and all subsequent terms will contain this factor also.

If m is negative or fractional, however, the series is infinite, *i.e.*, does not terminate. Under what conditions will it be convergent? In the absence of any obvious answer the first thing to investigate is the ratio of a_{n+1} to a_n. This is

$$\frac{(m-n+1)}{n}x=-x\left(1-\frac{m+1}{n}\right).$$

This ratio can be made to approximate to $-x$ within any desired standard by sufficiently increasing n, however large m may be. Thus, if x is less than 1 numerically there will in every case be a term in the series from and after which the ratio of a_{n+1} to a_n is less than 1. The series is therefore convergent provided x is less than 1 numerically.

Another important series is

$$1,\ \frac{x}{1!},\ \frac{x^2}{2!},\ \frac{x^3}{3!},\ \frac{x^4}{4!},\ \frac{x^5}{5!}\ \ldots\ \frac{x^{n+1}}{(n-1)!}\ldots\ \text{etc., etc., } ad.\ inf.$$

This is called the Exponential Series. In this case

$$\frac{a_{n+1}}{a_n}=\frac{x^n}{n!}\times\frac{(n-1)!}{x^{n-1}}=\frac{x}{n}$$

Now, however large x may be, there will always be some term in the series from and after which x/n is less than 1 numerically. This series is therefore convergent for *all* values of x.

The series

$$x,\ -\frac{x^2}{2},\ \frac{x^3}{3},\ -\frac{x^4}{4},\ \frac{x^5}{5}\ \ldots\ (-1)^{n+1}\frac{x^n}{n}\ \ldots$$
$$\text{etc., etc., } ad.\ inf.$$

is called the Logarithmic Series. Here

$$\frac{a_{n+1}}{a_n}=-\frac{nx}{n+1}=-x\left(\frac{n}{n+1}\right)$$

and this will always be less than 1 numerically provided x is less than 1 numerically. This series is therefore convergent for all values of x between plus and minus 1.

There is, of course, a host of other series which play a large part in applied mathematics, but these will be considered individually as they occur.

Examples.—Series.

1. Show that the series of which the nth term is $an+b$ is arithmetic. What is its first term, and the sum of the second fifty terms?

2. The first term of an arithmetic series is n^2-n+1, and the common difference is 2. Show

that the sum of n terms is n^3, and thence show that

$$1^3=1$$
$$2^3=3+5$$
$$3^3=7+9+11$$
$$4^3=13+15+17+19$$
etc., etc.

3. Prove that if the sum of n terms of a series is $a(r^n-1)$, the series is geometric. Find the first term and the common ratio.

4. Prove that in an infinite geometric series (common ratio less than 1) the ratio of any term to the sum of all that follow it is constant.

5. Show that the series of which the general term is $1/(n^2-x)$ is convergent except when x is the square of an integer.

6. Discuss the convergency of the series having as nth terms :—

(a) $1/(x+n-1)$

(b) $(1+n)/(1+n^2)$

(c) $\dfrac{3.5.7.\ \ .\ .\ .\ .\ (2n+1)}{4.7.10\ \ .\ .\ .\ .\ (3n+1)}x^n$

Answers to Examples in February Issue.

1. $+\infty$; $-\infty$; b/d ; b/d.
2. Discontinuity when $x=3$ and when $x=4$; $-\infty$; $+\infty$; $+\infty$; $-\infty$; 1 ; 1.
3. b/c ; b/c.
4. 3/8 ; 3/8 ; 3/8 ; 3/8 ; $+\infty$; $-\infty$.
5. 0.
6. The limit when $x \to a$ is $1/\sqrt{2a}$.

A Modified Beat Method of Comparing Two High-Frequency Oscillations.

WHEN it is desired to make an accurate comparison between the oscillation frequencies of two high frequency oscillators the method adopted is usually somewhat as follows: The oscillator under calibration is set so that the frequency of the generated oscillations differs somewhat from the standard, so as to produce an audible heterodyne note in the telephones. A musical note for comparison is produced by a tuning fork or by two independent high frequency oscillators, and the oscillator under calibration is adjusted by means of the beats between the two musical notes. When the beats vanish the difference between the two high frequencies is equal to the frequency of the musical note. A second reading is then obtained in the same way, and the mean of the two readings corresponds to the frequency of the standard.

The writer has recently devised a modification of this method which has the advantage that the correct calibration is obtained directly.

In this method a third oscillator is employed and the tuning fork or its equivalent is dispensed with. The third oscillator is used as an autodyne and is connected to the telephones or low frequency amplifier as the case may be.

The autodyne is arranged in reference to the other apparatus so that it picks up the signals both from the standard oscillator and also the oscillator under calibration, and it is adjusted so as to heterodyne these signals at some convenient frequency. Of the two notes which are audible in the telephones one will represent the difference between the frequency of the third oscillator and the frequency of the standard, and the other the difference between the third oscillator and the instrument under calibration. The two audible notes will beat together in the manner with which we are already familiar, and the beat frequency will represent the difference between the standard oscillator and the instrument under calibration.

The instrument under calibration is adjusted until the beats vanish and the two instruments are then in absolute synchronism.

In applying the method in practice it is necessary to guard against the possibility that beats may be obtained when the frequency of the autodyne is adjusted midway between the frequencies of the other two oscillators. This apparent ambiguity can be disposed of, however, by slightly altering the adjustment of the autodyne. If the correct adjustment has been obtained the beat will persist at a constant frequency while the musical note is varied, whereas if the adjustment is incorrect the beats will vanish altogether.

K.E.E.

Abstracts and References.

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PROPAGATION OF WAVES.

EINE URSACHE DER ÄNDERUNG DES POLARISATIONZUSTANDES KURZER WELLEN (A cause of the alteration of the state of polarisation of short waves). — N. von Korshenewsky. (*Zeitschr. f. Hochfrequenz.*, 28, December, 1926, pp. 184 185.)

In short wave reception it has been observed that the incoming waves differ from those transmitted with regard to their state of polarisation. If linearly polarised waves are sent out, they arrive at the receiver, in general, elliptically polarised in a plane perpendicular to the direction of propagation, or in a special case, linearly polarised but with a different direction of oscillation from that transmitted. There thus arises on the way from transmitter to receiver an oscillation component perpendicular to the direction of oscillation and to the direction of propagation of the wave sent out. This phenomenon has been attributed by some physicists to the earth's magnetic field influencing the plane of polarisation in a way corresponding to the Faraday effect in optics. This explanation of the rotation solely through the magnetic effect is opposed, however, by various theoretical considerations. It has also been contradicted by the results of experiment; for example, the effect to be expected on altering the direction transmitter-receiver with regard to the earth's magnetic field was not found. (Pickard, *Proc. Inst. Radio Eng.*, 14, 205-212, 1926.)

In this article, a cause for the influencing of the direction of polarisation of short waves during their propagation through the atmosphere is found in the azimuthal deviations the rays undergo on their way from transmitter to receiver.

The introduction of an oscillation component perpendicular to the direction of oscillation of polarised waves and perpendicular to the direction of propagation cannot be explained by means of reflection and refraction in the layers of the atmosphere so long as this reflection and refraction is considered to occur only in the vertical plane passing through transmitter and receiver, *i.e.*, so long as the path of the electromagnetic ray is thought of as a plane curve lying in this vertical plane. Rotation of the plane of polarisation can then only be effected by refraction and reflection when the plane of polarisation either coincides with the plane of incidence (understood as in optics) or is perpendicular to it. If, however, the direction of oscillation is inclined to the plane of incidence at some angle between 0° and 90°, then with diverse refraction and reflection of the parallel and perpendicular components a rotation will be possible. As a matter of fact, the electromagnetic ray cannot possibly describe a plane curve in the vertical plane between transmitter and receiver, for this could only be the case if the layers had the same refractive power and were absolutely concentric with the earth's surface and if all reflecting surfaces were orientated orthogonally to this vertical plane. This case, of course, does not occur in nature. On the contrary, the electromagnetic ray travelling between transmitter and receiver must undergo lateral deviations and curvatures brought about by a gradation of density in the ions or electrons in a direction perpendicular to the vertical plane passing through transmitter and receiver, and further by reflections taking place at surfaces having diverse angles of inclination with the vertical plane. Consequently the electromagnetic ray, undergoing deviation in an azimuthal as well as a vertical direction, describes a curve that does not lie in the vertical plane through transmitter and receiver, but in planes inclined to it. The trajectory of the ray represents a complicated space curve. However, with refractions and reflections taking place in planes inclined to the vertical, the direction of oscillation that may be vertical or horizontal at the transmitter is inclined relatively to the plane of incidence to the refracting or reflecting layers, so that resolution into two components in the plane of incidence and perpendicular thereto is possible. Since, however, the refracting and reflecting conditions with regard to these two components are in general different, the refracted or reflected ray that arrives at the receiver will be in a state of polarisation that has changed relatively to the incident wave on account of the difference in the refractions or reflections of the two components. Thus, for instance, if with a lateral refraction there is merely an alteration of the amplitude relation between the components oscillating in the plane of incidence and that at right angles to it, then the plane of polarisation of the refracted ray will be rotated through an angle, but if, on the other hand, as will generally be the case, there is also a phase displacement between these two components, then the refracted ray will be elliptically polarised.

AU SUJET DE LA NOUVELLE FORMULE DE PROPAGATION DE KIEBITZ (On Kiebitz's new propagation formula). — R. Mesny. (*L'Onde Electrique*, 5, December, 1926, pp. 650-656.)

Kiebitz has recently made out a new theory of wave propagation around the earth (*Ann. d. Phys.*, 80, 1926, 728, these abstracts *E.W. & W.E.*, January, 1927, p. 49), which leads to the formula :—

$$E\frac{\text{volt.}}{m} = 0.377\frac{h}{\lambda}\ \frac{I\ (\text{amp})}{d\ (km)}\ \frac{\gamma\ (\text{rad.})}{\sin\gamma}$$

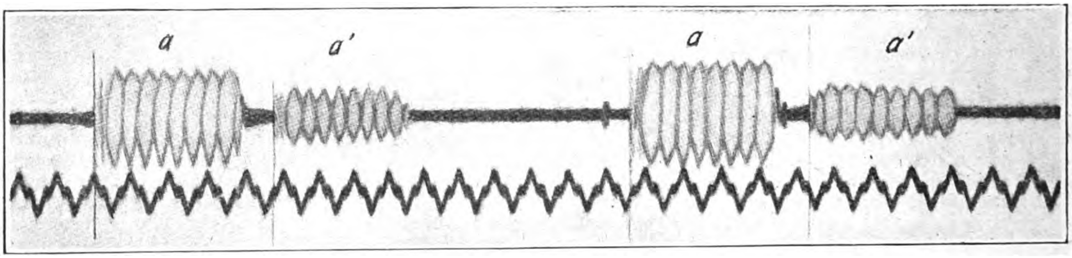
Where E is the electric field at a point on the earth and γ the arc of the great circle joining this point to the transmitter. This formula gives numerical values pretty near those observed for the maximum fields at night, both for the long

waves from Rocky Point heard at Berlin and for the very short waves from Nauen picked up at Buenos Aires. The author, however, sees in this agreement only a chance coincidence, the object of this article being to show that Kiebitz's theory is entirely fanciful.

The theory is obtained from Maxwell's equations by introducing the simplification that the electric and magnetic fields are practically equal at each instant at some distance from the transmitter, and Mesny here does the calculation again by a different method which shows that this simplification is incompatible with Maxwell's equations and the resulting theory cannot in any way correspond to reality.

NEUES ÜBER, DIE AUSBREITUNG VON KURZEN WELLEN (New results on the propagation of short waves).—E. Quäck. (*Zeitschr. f. Hochfrequenz.*, 28, December, 1926, pp. 177, 178.)

During printed reception at Geltow of the American short wave station 2XT (λ=16.175 m.), disturbing double signs were often found, the time of whose retardation permitting the conjecture that they are caused by waves that have traversed a longer path in the opposite direction round the earth. Such double signs have been recorded graphically, a specimen oscillogram being reproduced where *a* are the principal signs, and *a'* the double signs.



Further, with the 8kW short wave transmitter at Nauen and a wavelength of 15 metres, signs were successfully sent right round the earth and likewise recorded. For this the signs required on an average .138 second, giving a path of 41,200 km., assuming the normal velocity of light. This path would correspond to a great circle around the earth at a height of about 182 km.

WIRELESS COMMUNICATION AND TERRESTRIAL MAGNETISM.—C. Chree. (*Nature*, 119, 15th January, 1927, pp. 82, 83.)

Some remarks from the point of view of a magnetician on a conducting layer in the upper atmosphere, firstly with regard to the history of the conception, and then on the evidence for the existence of the layer and its varying conductivity that is derived from the observations of terrestrial magnetism.

We are reminded that estimates of the altitude of a stratum of high electrical conductivity were made long before the time of wireless communication. In 1790 Cavendish obtained on strictly scientific grounds an estimate of from 84 to 114 km. for the altitude of an auroral arc. Prof. Störmer's methods of high precision have supplied numerous results for the lower level of auroræ, which have long been well known, the levels showing variations with similar limits to those recently obtained by Appleton and Barnett. Dr. Chree further points out that the continual existence of high electrical conductivity in the upper atmosphere was first advanced as an hypothesis by Balfour Stewart, about 1882, and that if any name is to be associated with a conducting layer in the upper atmosphere, it should be neither Heaviside's nor Kennelly's, but Stewart's.

With regard to arguments for the existence of the conducting layer on the side of terrestrial magnetism, apart from auroræ, the strongest in the opinion of the writer is derived from the observed large universal increase of the diurnal variation of the magnetic elements as we pass from sunspot minimum to sunspot maximum. It is this argument that has led practically all, if not all magneticians, to accept the upper atmosphere as the seat of electrical currents to which the regular diurnal variation of the magnetic elements is due. The results further show that, whether in years of many or of few sunspots, the regular diurnal variation tends to be larger on disturbed than on quiet days. This seems to imply that in addition to local irregularities in the conductivity of the conducting layer, due presumably to the irregular distribution of the sources of ionisation, there is during magnetic disturbance a decided increase in the average conductivity. This phenomenon is comparatively trifling in Southern England, but increases in importance as we go North, which suggests that the natural place to study the relationships between wireless and magnetic phenomena is not the South of England but the North of Scotland, or still more northern regions, where magnetic disturbance is much larger and more persistent.

Referring to this letter in *Nature* of 29th January, p. 157, Dr. Eccles explains why he chose the name "Heaviside layer" for the upper portion of the atmosphere the aid of which is so often invoked to account for many of the facts of wireless telegraphy. In the spring of 1902 Heaviside raised the question as to whether Mr. Marconi's recent success in telegraphing from Cornwall to Newfoundland might not be due to the presence of a permanently conducting upper layer in the atmosphere. The suggestion was gradually approved during the years that followed, and about 1910 Dr. Eccles used the convenient name "Heaviside layer" in

a paper, to indicate the portion of the atmosphere that functions so usefully for the purposes of wireless telegraphy. The existence of a conducting stratum in the atmosphere and its probable connection with the aurora must have been surmised by every observer of electric discharge in rarefied gases even before the date of Cavendish, also Balfour Stewart suggested that a conducting layer might have to do with certain variations of the magnetic elements, but there is as yet no proof that the auroral layer is the same as the Stewart layer, or that either of them is the same as the physically present layer called for convenience the Heaviside layer.

Dr. Eccles wishes to urge that full advantage be taken of the solar eclipse next June for learning more about the Heaviside layer.

THE HEAVISIDE LAYER.—E. V. Appleton. (*Wireless World*, 20, 5th January, 1927, pp. 2-4.)

Prof. Appleton explains in simple language how he and Mr. Barnett proved experimentally that the layer exists.

EINFLUSS DER SONNENFINSTERNIS VOM 14 JANUAR 1926 AUF DIE FORTPFLANZUNG DER DRAHTLOSEN WELLEN (Effect of the sun's eclipse of 14th January, 1926, on the propagation of wireless waves). *Zeitschr. f. Hochfrequenz.*, 28, December, 1926, pp. 189, 190.)

In the Dutch East Indies a whole series of tests were organised by the Postal Service for the moment when the eclipse shadow passed over these islands. The results of the observations, however, were in general negative, *i.e.*, no effect of the sun's eclipse on the propagation of wireless waves could be detected with any degree of certainty. This result might be expected at stations some distance from the shadow track, but the same absence of definite effect was observed at Tarakan and Palembang, right in the path of the shadow. A single exception occurred at Rantja-ekek, where the signals from Tananarive (15,600 m.) and Bengkalis (1,650 m.) were received much weaker than usual. On the other hand, the signals from Saigon came in more strongly than usual at this station, as also did those from Malabar at Sitoebondo.

RADIO SIGNAL STRENGTH AND TEMPERATURE.—L. Austin and I. Wymore. (*Proc. Inst. Radio Engineers*, 14, December, 1926, pp. 781-784.)

Continued daily observations at Washington on signals from Tuckerton and New Brunswick appear to prove that there is some kind of inverse relationship between signal strength and local temperature, though the effect is often masked by other influences. Curves are given showing the degree of temperature—signal relationship for the year 1924. In the curve of monthly averages, the connection between signal and temperature is said to be evident, the average signals of February being more than twice as strong as those of July, and considerably stronger than would be required by the inverse distance law. The day-by-day relationship is less satisfactory, varying from fairly clear in the winter months to obscure in midsummer.

ADDRESS OF THE PRESIDENT, SIR ERNEST RUTHERFORD, AT THE ANNIVERSARY MEETING, 30th November, 1926. (*Proc. Roy. Soc.*, 113, A, January, 1927, pp. 481-495.)

Reference is made to recent striking advances in radio communication and to the new avenues of research in the electrical state of our atmosphere that are being opened up by the study of the mode of propagation of wireless waves over the earth.

ÜBER DEN DURCH DIE HESS'SCHE HÖHENSTRAHLUNG BEDINGTEN IONISATIONS—UND LEITFÄHIGKEITSZUSTAND DER HÖHEREN LUFTSCHICHTEN (On the state of ionisation and conductivity of the upper layers of the atmosphere, brought about by the Hess vertical radiation). H. Benndorf. (*Physik. Zeitschr.*, 27, 1st November, 1926, pp. 686-692.)

According to our present knowledge, the following radiations call for consideration as ionisers of the upper layers of the atmosphere :—

1. The ultra-violet of sunlight.
2. Corpuscular rays from the sun.
3. The Hess vertical radiation.

The effects of sunlight and corpuscular radiation from the sun have been investigated respectively by Swann (*Terr. Mag.*, 21, 1, 1916) and Elias (*Zeitschrift. f. Hochfrequenz.*, 27, 66, 1926). This article considers the effect on the conductivity of the upper atmosphere of the penetrating vertical radiation.

The subject of this radiation is of particular importance as it is the only radiation of the three that would remain unaltered by day and night. The ultra-violet of sunlight, of course, does not come into question at all for night ionisation, while the action at night of corpuscular radiation from the sun is at the most doubtful. It is true Elias has put forward the suggestion that this radiation is deviated by the earth's magnetic field to the night side of the earth, producing there marked ionisation. The author, however, is of the opinion that, apart from the fact that we know very little for certain about this radiation and its magnetic deviability, it is most improbable that it occurs in the atmosphere distributed at all uniformly, which would have to be the case to account for the state of ionisation of the atmosphere, during the night as well, that is to be concluded from the propagation of electric waves.

Assuming a cosmic radiation with a mass absorption coefficient between the limits $2.2 . 10^{-3}$ and $4.5 . 10^{-3}$ cm.^{2}/g, the ionisation and conductivity of the atmosphere are here calculated for different heights. It is found that at a height of 100 km. the conductivity (for direct current) assumes a value about 10^{10} times that at the earth's surface, the air at this height conducting as well as dry ground. There is also a very marked rise in the conductivity between 70 and 80 km. Thus the Hess vertical radiation provides a source of ionisation by night as well as by day that entirely suffices, solving the problem of the night ionisation for which no explanation was hitherto forthcoming—or only a very unsatisfactory one.

Beitrag zum Problem der leitfähigkeit der Atmosphäre (Contribution to the problem of the conductivity of the atmosphere).—R. Stoppel. (*Physik. Zeitschr.*, 27, 1st December, 1926, pp. 755-761.)

Observations carried out both at Hamburg and in the North of Iceland showed the electrical conductivity of the air to have a daily period with a maximum between 4 and 6 in the morning local time, uninfluenced by the period of midnight sun, but much reduced at times of auroræ. The variations of conductivity are not dependent upon changes of sunlight, temperature, pressure or degree of saturation of the air, but are thought to be due to a cosmic factor at present unknown.

A Dynamical Theory of the Electromagnetic Field. (*Nature*, 119, 22nd January, 1927, pp. 125-127.)

Clerk Maxwell's own abstract of his historic paper communicated to the Royal Society on 27th October, 1864, reprinted from the Proceedings of 8th December, 1864.

This paper constitutes the opening chapter in the history of radio communication. It shows that electric and magnetic effects cannot be produced instantaneously at a distance, but must be propagated through space with the velocity of light, also the wave-nature of these electrical disturbances and their mode of propagation. The famous equations contain the complete theory of electrical waves and their transmission through space.

Über die Eindeutigkeit der Lösung der Maxwellschen Gleichungen (On the unambiguousness of the solution of Maxwell's equations.—A. Rubinowicz. (*Physik. Zeitschr.*, 27, 15th November, 1926, pp. 707-710.)

PROPERTIES OF CIRCUITS.

Untersuchungen über die Schwingschaltung von Numans-Roosenstein (Experiments with the Numans-Roosenstein oscillatory circuit).—E. Mittelmann. (*Zeitschr. f. Hochfrequenz.*, 28, December, 1926, pp. 188-189.)

In the course of an investigation on double-grid valves, the author made a study of the Numans circuit in order to obtain information as to the oscillation relations under different working conditions. The characteristics of the space charge current for several tetrodes coming into the investigation were obtained with the circuit arrangement shown. Tetrodes with a thorium filament were found to behave somewhat irregularly. A stable state of oscillation was first obtained when a wolfram filament was employed, and the Telefunken valve RE26 was used for the investigation. A series of experiments with this valve are described here: the dependence of oscillation amplitude on heating current, the oscillations being found to suddenly cease when the heating current reaches a certain value, also the dependence of oscillation amplitude on the space charge tension applied, and on the wavelength (when here, too, the oscillations suddenly break down for a certain position of the condenser). The results are shown graphically.

The Output Characteristics of Amplifier Tubes.—J. Warner and A. Loughren. (*Proc. Inst. Radio Engineers*, 14, December, 1926, pp. 735-755.)

Discussion of the factors determining amplification, the use of plate characteristic curves for calculating output, the conditions for maximum output with low distortion, the calculation of the maximum undistorted output, and the relation of valve design to power output.

Some of the constants of the more commonly used radiotrons are tabulated; the first half of the table shows the constants of the valves themselves and the second half gives the maximum undistorted output (assuming not more than 5 per cent. second harmonic current in the load), the load resistance at which the maximum output is obtained, the input grid voltage required to produce this output, and the amplification of the valve with this same load resistance.

Aperiodic H.F. Amplification.—H. Kröncke. (*Wireless World*, 20, 5th January, 1927, pp. 27-28.)

Further notes on the work of von Ardenne and Heinert.

Supersonic Transformers. — N. McLachlan. (*Wireless World*, 20, 5th January, 1927, pp. 21-24.)

Part V., dealing with the influence of input impedance of valves.

Resistance-coupled Relay Circuit.—N. McLachlan. (*Wireless World*, 20, 19th January, 1927, pp. 67-70.)

Description of a form of valve circuit suitable for actuating a relatively slow operating relay for remote control work.

Simple Resonance Curves and their Modification by Valve Circuits.—E. Mallett. *E.W. & W.E.*, 4, February, 1927, pp. 93-103.)

TRANSMISSION.

Zur Theorie der Seitenbänder (On the theory of side bands).—R. Hiecke. (*Zeitschr. f. Hochfrequenz.*, 28, December, 1926, pp. 185-187.)

If the carrier wave of a broadcast transmitter is modulated by superimposing a note frequency, there appear besides the carrier wave of frequency ω_1 also waves of frequency $\omega_1+\omega_2$ and $\omega_1-\omega_2$, as is seen from the equation for the modulated wave:—

$$I=(A+B \sin \omega_2 t) \sin \omega_1 t = A \sin \omega_1 t + B/2 \cos (\omega_1-\omega_2)t - B/2 \cos (\omega_1+\omega_2)t.$$

The side frequencies for the whole range of the note frequencies together make up the side bands of the carrier wave. Undistorted note reproduction is then only obtained in the receiver when the carrier wave is present with both side frequencies in their original amplitude relations; accordingly part of the latter must on no account be suppressed by too great selectivity. Frequently, however, one meets with the view that with the reception of

both side bands the frequencies $\omega_1+\omega_2$ and $\omega_1-\omega_2$ together produce a beat note of frequency $(\omega_1+\omega_2)-(\omega_1-\omega_2)=2\omega_2$, *i.e.*, the octave of the modulating frequency, and for this reason one of the two side bands has to be suppressed in the transmitter. This article shows mathematically that this view is entirely incorrect.

Die Strahlung der komplizierten rechtwinkeligen Antennen mit gleichbeschaffenen Vibratoren (The radiation of complicated rectangular antennæ with similarly disposed vibrators).—M. Bontsch-Bruewitsch. (*Ann. der Physik*, 81, 1926, pp. 425-453.)

By a complicated antenna is meant here an aerial, consisting of a number of vibrators and a system of conductors, by which the energy is led. The author calls all antennæ "rectangular," the wires of which are arranged perpendicular to one another in three directions only. In this case, the axes of the radiating vibrators coincide with one of these directions. The radiation resistance R of an antenna of this kind can be defined as the ratio of the output P radiated to the square of the sum of the currents at the anti nodes of the vibrators. In the case of n similarly disposed vibrators loaded with equal current this resistance is :—

$$R=\frac{P}{(ni)^2}$$

The losses in general are distributed unequally between the different vibrators, but sometimes it is practically more advantageous to have to deal with a mean value of the radiation resistance of each vibrator, defined as follows :—

$$r=\frac{P}{ni^2}=nR$$

This paper calculates the output radiated for such an antenna system.

Low-power Crystal-controlled Transmitters. J. Clayton. (*Q.S.T.*, 11, January, 1927, pp. 14-18.)

Zur Konstruktion der Radiospiegel (Construction of the radio reflector).—W. Tatarinoff. (*Zeitschr. f. Hochfrequenz.*, 28, October, 1926, pp. 117-120.)

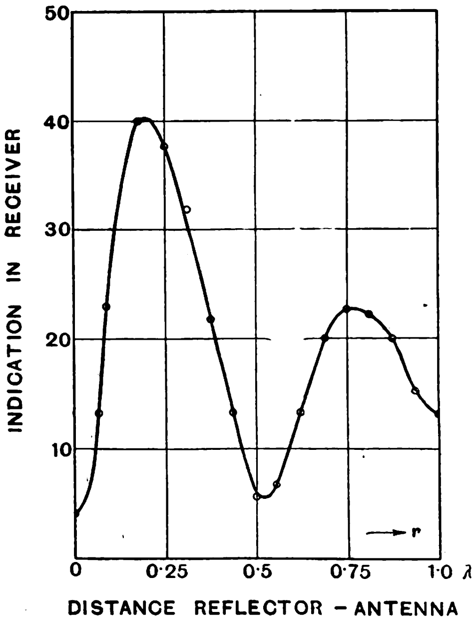
When constructing the reflector for directional radio transmission, it is important to know the phase displacement on the reflection of the wave from the resonating conductors. This phase displacement ψ depends in general on the tuning of the resonator, on its form and its position with respect to the antenna. The dependence of ψ upon r, the distance between antenna and resonator, was investigated experimentally by the author for the case when the two rectilinear conductors are a half-wave in length. The investigation, which is described, showed that ψ is a function of r, a graph of the relationship being given—showing that when $r=0$, $\psi=180°$, and that with increasing r, ψ approaches asymptotically to 90°. This curve enables the distance to be calculated at which the reflector must be placed for the reflected ray and that falling directly on the receiver to agree in phase. The solution of the equation :—

$$\psi(r)+4\pi r=2k\pi$$

that is required is most easily obtained graphically as the point of intersection of the two curves—

$$y=\psi(r) \text{ and } y=2\pi(k-2r).$$

The calculated values for different whole numbers k do not exactly correspond, however, to the current maxima in the receiver, since with the decrease of the distance r, the amplitude of the resonator is increased. The maxima in the receiver therefore correspond to somewhat smaller distances than those obtained from calculation. These displacements of the maxima should gradually diminish as r becomes larger, *i.e.*, as k increases. This was proved to be the case in the experimental tests, when the resonator was first placed close up to the antenna and then gradually removed to the distance $r=\lambda$. The changes of amplitude in the receiver as the distance increased are represented in the figure below :—



Some composite antennæ and reflectors are then examined—a grid reflector being found not nearly so good as a plane reflector of tinfoil or a tuned reflector with four conductors.

Lastly, from the fact that ψ is a function of r, some further conclusions are drawn with regard to the construction of parabolic mirrors.

Richtcharakteristiken von Antennenkombinationen (Directional characteristics of antenna combinations).—A. Esau. (*Zeitschr. f. Hochfrequenz.*, 28, pp. 1-12 and 147-156.)

Second and concluding parts of an article begun in *Zeitschr. f. Hochfrequenz.*, 27, p. 142 (these abstracts *E.W. & W.E.*, September, 1926, p. 570). While the first part derived a general formula for the directional characteristic of the combination of two antennæ, discussing the special cases of two antennæ either both undirectional or both

directional, the second part considers the combination of a directional and an undirectional antenna from both the theoretical and practical view-point, also the production of the cardiode characteristic by combining three undirectional antennæ and the double frame arrangement. The third and last part further discusses the combination of three undirectional antennæ (Braun's triangular arrangement), and the Marconi bent antenna, also the arrangement of two bent antennæ in series and in parallel, the characteristics of the combinations being shown to assume a somewhat different form when the distance between transmitter and receiver is taken to be finite.

RECEPTION.

NOTES ON THE DESIGN OF RESISTANCE-CAPACITY COUPLED AMPLIFIERS.—S. Harris. (*Proc. Inst. Radio Engineers*, 14, December, 1926, pp. 759-763.)

An analysis of the coupling in the resistance-capacity coupled amplifier is given, in which the variation of the voltage ratio with frequency is considered. A method is given for determining the values of the resistances and capacities for which the variation of voltage ratio over a given frequency range will be a definite and known amount.

LA SUPPRESSION DES PARASITES EN T.S.F. PAR LES FILTRES ACOUSTIQUES (Eliminating disturbances in wireless telegraphy by means of acoustic filters).—A. Nodon. (*L'Onde Electrique*, 5, December, 1926, pp. 657-663).

The application of the principles of electromagnetic filters employed in wireless telegraphy to eliminate atmospherics has enabled M. Canac (*Journ. de Physique*, 8, 6, June, 1926) to institute acoustic filters for getting rid of troublesome harmonics in the high, low and medium regions respectively of the audio range. The filters, coupled in pairs, free telephonic reception from alien sounds, after which it can be amplified as much as desired by means of valves.

THE DESIGN OF A HETERODYNE TYPE LOW FREQUENCY GENERATOR.—H. Kirke. (*E.W. & W.E.*, 4, February, 1927, pp. 67-76.)

STEREOPHONIC RECEPTION.—M. von Ardenne. (*Wireless World*, 20, 26th January, 1927, pp. 117-118.)

THE PERFORMANCE OF AMPLIFIERS.—P. K. Turner. (*E.W. & W.E.*, 4, February, 1927, pp. 77-80.)

HIGH QUALITY REPRODUCTION. — R. Denman. (*Wireless World*, 20, 26th January, 1927.)

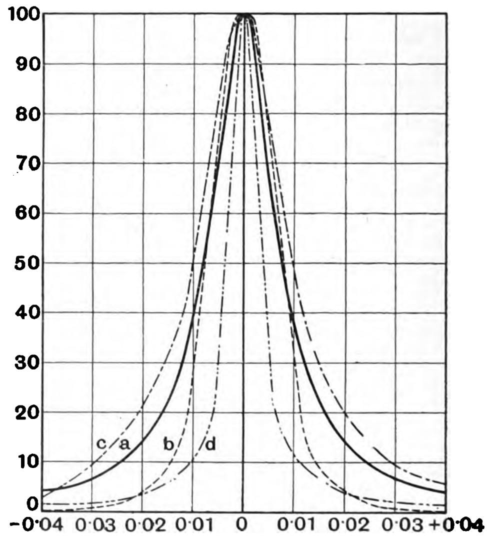
Description of a combination broadcast-gramophone equipment.

A SHORT-WAVE SUPER-REGENERATIVE RECEIVER.—E. Dallin. (*Q.S.T.*, 11, January, 1927, pp. 40-43.)

FIVE-METRE RECEIVERS.—R. Kruse. (*Q.S.T.*, 11, January, 1927, pp. 36-39.)

ÜBER INDUKTIVE KOPPLUNG IN EMPFANGSKREISEN (On inductive coupling in receiving circuits). —D. v. Seelen. (*Zeitschr. f. Hochfrequenz.*, 28, October, 1926, pp. 114-117.)

From the tension equations of two inductively coupled circuits, the relation is deduced between primary operating tension and secondary current. Assuming the different constants to be of about the same order of magnitude as they occur in radiotelegraphic receiving circuits, the values of the current received with different degrees of coupling are calculated. The current received at the coupling maxima is of the same value as with resonance and optimum coupling. The sharpness of tuning of the circuit combination with different degrees of coupling is found by comparison with the resonance curve of a single circuit. The results are shown in the figure below.



Resonance curves calculated for equal (optimum) current received with unaltered circuit adjustment.

For all curves I^2 is a maximum when $\omega = 5.10^6 \sim$ 375m.

(*a*) ——— *resonance curve of the single circuit* $\delta_0 = 2.10^4$ *sec*$^{-1}$.

(*b*) . . . . . . *resonance curve with* $k = 0.0056$, $\delta_0 = 2.10^4$, $\delta_1 = 1.10^4$ *sec*$^{-1}$.

Path of I^2 in the coupling maximum with $k = 0.5$; δ_0, δ_1 as before :

(*c*) — · — · — · — *natural frequency of the circuit* $< \omega$.

(*d*) — · · — · · — · · *natural frequency of the circuit* $> \omega$.

With the help of the formula for the primary current as a function of the primary tension the physical significance of the relations suggested is pointed out.

DEVELOPMENTS IN TUNED INVERSE DUPLEX.—D. Grimes. (*Q.S.T.*, 11, January, 1927, pp. 9-13.)

THE PERFORMANCE OF MODERN BROADCAST RECEIVERS.—P. K. Turner. (*Electrical Review*, 99, 31st December, 1926, pp. 1072-1073.)

An account of work at the Research Department of Burndept Wireless, Ltd.

VALVE DESIGN AND THERMIONICS.

DETERMINATION OF ELECTRONIC CHARGE FROM MEASUREMENTS OF SHOT-EFFECT IN APERIODIC CIRCUITS.—N. Williams and H. Vincent. (*Physical Review*, 28, December, 1926, pp. 1250-1264.)

An outstanding difficulty in the measurement of electronic charge from shot-effect in a tuned circuit has been regeneration into this circuit. Former methods of dealing with that feature have added tedious computations to Schottky's original calculation. The solution presented here yields the result in such a form that much of the labour is eliminated, the solution being of great mathematical simplicity and measurement of high-frequency resistance and resonance frequency becoming unnecessary.

AN EFFECT OF LIGHT ON THE ELECTRON EMISSION FROM HOT FILAMENTS.—W. Crew. (*Physical Review*, 28, December, 1926, pp. 1267-1274.)

The increase in the electron emission from hot, oxide-coated platinum filaments when illuminated by the full radiation from a water-cooled quartz mercury arc was measured, for different filament temperatures, as a function of potential between filament and anode. The photo-electron currents were large enough to be readily measurable with a galvanometer, measurements on one filament showing the photo-electron current increasing with potential to a maximum of about 14 volts. No photo-electric fatigue was observed. It was found that, for the most part, the photo-currents are due to radiations of wavelengths shorter than $\lambda 3{,}000$. Plain platinum and tungsten filaments were tried, but only oxide-coated filaments gave an appreciable emission due to the light. It is suggested that the action of the light is to free electrons from a thin film of metal of which the work function varies with temperature of the filament.

THE UX-213 RECTRON AND THE UX-874 VOLTAGE REGULATOR.—O. Pike. (*Q.S.T.*, 11, January, 1927, pp. 44-46.)

FILAMENTLESS VALVES FOR A.C. SUPPLY. (*Wireless World*, 20, 26th January, 1927, pp. 115-116.)

Discusses the introduction of an indirectly heated cathode to eliminate the filament battery.

MEASUREMENTS AND STANDARDS.

CONTRIBUTION À LA REALISATION D'UN ETALON DE FAIBLE CAPACITÉ (Contribution to the production of a standard of small capacity). —F. Bedeau. (*L'Onde Electrique*, 5, December, 1926, pp. 613-649.)

A study of the measurement of small capacity at high frequency. It is shown that extremely sensitive methods exist to-day for measuring very small variations of capacity and yet the values given for various physical constants differ considerably from one another. The fact is all capacities are at present evaluated in terms of standards of inductance and resistance, a procedure that becomes necessary when the capacity to be measured is large, since an air condenser standard of large capacity is difficult to realise. This, however, is no longer the case for a standard of low capacity, and in this paper the author describes his attempt to produce such an air condenser standard capable of employment in high frequency measurements, with which he believes very small variations of capacity are measurable with greater accuracy than that at present obtained. This number contains the introduction and first two chapters of the work. In the first chapter, the author gives his reasons for choosing a cylindrical condenser as standard of capacity and discusses the different sources of error, and in the second chapter he explains how the ratio of the radii is obtained and gives the results of his measurements.

SHIELDED OSCILLATOR FOR HERTZIAN WAVES.—J. Tykocinski-Tykociner. (*Physical Review*, 29, January, 1927, p. 217.)

Abstract of a paper presented at the Chicago meeting of the American Physical Society, November, 1926.

A thermionic tube is mounted at each end inside a brass cylinder in contact with the cold electrode. The grids of the tubes are connected by means of an insulated rod placed concentrically in the cylinder. The electromagnetic field of the oscillator is confined to the space inside the cylinder, where a standing wave is produced along its axis with a potential node in a plane dividing the length of the cylinder in two equal parts. The variation of frequency is produced by condensers mounted inside the cylinder. The cylinder is closed at each end by means of rotating shielding caps which serve as dials for the tuning mechanism. Measurements on antennæ or Lecher wires were made undisturbed by the stray field of the oscillator, by connecting them with two points of the rod, reached through holes made in the cylinder on both sides of the nodal plane. Standard 5 and 50-watt oscillating tubes were used. With an oscillator having a cylinder 100 cm. long and 7.3 cm. in diameter, a frequency of 60×10^6 to 65×10^6 was produced. A shorter cylinder 66 cm. long and 4.8 cm. in diameter gave a frequency of 85×10^6.

THE RESISTANCE OF COPPER WIRES AT VERY HIGH FREQUENCIES.—W. Roberds. (*Physical Review*, 29, January, 1927, pp. 165-173.)

At frequencies of the order of 10^7 cycles the distributed capacity of single loops of wire may cause sufficiently unequal current distribution in the loop to account for large apparent discrepancies between observed and calculated resistances. For a given frequency, more uniform current distribution is gained by decreasing the size of the loop and simultaneously increasing the capacity of the tuning condenser. Curves are plotted with ratio of observed to calculated resistance as ordinate and condenser setting as abscissa. For No. 20

copper wire at 0.86×10^7 cycles the ratio increases to at least 1.05 as the current distribution along the wire is made more and more nearly uniform. For No. 16 oxide-coated copper wire the ratio reduces to at least 1.35. The discrepancy in both cases is accounted for by the same value of condenser resistance. Observed resistance of a given loop is shown to vary greatly as condenser resistance is changed.

Since curves run on bright copper wire coincide with curves run on exactly the same wire after it had gained a heavy coating of oxide, it can be definitely stated that the presence of oxide has no appreciable effect on the resistance.

RADIO-FREQUENCY MEASUREMENTS. (*E.W. & W.E.*, 4, February, 1927, pp. 108-110.)

A book of importance to radio experimenters entitled "The Theory and Practice of Radio Frequency Measurements: a Handbook for the Laboratory and a Text-book for Advanced Students," by E. B. Moullin, has recently been published. The book is reviewed here, chapter by chapter, by Mr. Dye; also in *Nature* of 29th January, p. 155, there is a brief article on the book by Prof. Appleton.

SIGNAL FADING MEASUREMENTS.—R. L. Smith-Rose. (*Wireless World*, 20, 12th January, 1927, pp. 32-37.)

The measurement of signal fading is briefly discussed and practical details are given for constructing and calibrating the necessary apparatus.

AERIAL TESTING.—J. Catterson-Smith. (*Journal of the Indian Institute of Science*, 9B, III., pp. 21-28.)

Description of an extension of a method of testing due to Dr. Eccles ("Handbook of Wireless Telegraphy and Telephony," 2nd edition, 1918, 121). Graphical representation of aerial tuning characteristics is used to show the linear relation between tuning inductance and the reciprocal of the tuning capacity.

The use of a high frequency bridge method of determining the tuning characteristics and aerial resistance is explained.

STANDARD FREQUENCY TRANSMISSION IN AUSTRALIA.—H. Stowe. *Q.S.T.*, 11, January, 1927, pp. 34-35.)

SIMPLIFIED S.L.F. AND S.L.W. DESIGN.—O. C. Roos. (*Proc. Inst. Radio Engineers*, 14, December, 1926, pp. 773-780.)

A CALORIMETRIC METHOD OF MEASURING DIELECTRIC LOSSES AT HIGH FREQUENCIES.—G. Owen. (*Journ. Opt. Soc. Amer. and Rev. Sci. Inst.*, 13, December, 1926, pp. 725-726.)

SOME NEW COIL IMPEDANCE DIAGRAMS.—W. Barclay. (*E.W. & W.E.*, 4, February, 1927, pp. 87-92.)

A SHORT-WAVE PRECISION WAVEMETER. (*Q.S.T.*, 11, January, 1927, pp. 43 and 46.)

SUBSIDIARY APPARATUS AND EQUIPMENT.

THE ACOUSTIC PROBLEMS OF MICROPHONES AND LOUD-SPEAKERS. (*E.W. & W.E.*, 4, February, 1927, pp. 106-107.)

Informal discussion at I.E.E. Wireless Section.

A DIRECT RADIO CONTROL RELAY.—R. Kruse. (*Q.S.T.*, 11, January, 1927, pp. 19-21.)

H.T. AND L.T. FROM A 250-VOLT D.C. SUPPLY.—A. Robertson. (*E.W. & W.E.*, 4, February, 1927, pp. 111-113.)

A HIGH VOLTAGE DIRECT CURRENT GENERATOR.—S. Mackeown. (*Journ. Opt. Soc. Amer. and Rev. Sci. Inst.*, December, 1926, pp. 727-729.)

DRY BATTERIES FOR RADIO PURPOSES. (*Electrical Review*, 100, 7th January, 1927, pp. 3-5.)

Some impressions of a visit to the Woolwich works of Siemens Bros. & Co., Ltd., and their methods of manufacture.

EFFECT OF WORKING ON THE PHYSICAL PROPERTIES OF TUNGSTEN.—J. Avery and C. Smithells. (*Phys. Soc. Proc.*, 39, 1, December, 1926, pp. 85-96.)

GENERAL PHYSICAL ARTICLES.

PIEZO-ELECTRICITY OF CRYSTAL QUARTZ.—L. Dawson. (*Physical Review*, 29, January, 1927, p. 216.)

Abstract of a paper presented at the Chicago meeting of the American Physical Society, November, 1926.

Measurements with a quadrant electrometer of the piezo-electric charge in optically perfect crystal quartz have shown that the different specimens of quartz may produce charges of different magnitude. The piezo-electric charge appeared to be an integral effect over the surface since an exploration of the surface by an approximation to a point contact showed that charges varying in magnitude and sign may be produced on adjacent portions of the surface. The piezo-electric charge increased as the temperature was raised from room temperature to 60° C. and decreased thereafter to 576° C. where it disappears. The cooling curves show a lag. A relation between the pyro- and piezo-electric effects is pointed out. The piezo-electric charges on surfaces variously oriented with respect to the optic axis showed a characteristic distribution hitherto unsuspected and not explainable by simple theory. This characteristic distribution lead to an accurate method for determining the direction of the electric axes of quartz.

NEUE KUNSTGRIFFE IN DER VACUUMTECHNIK (New artifices in vacuum technique).—M. Schirmann. (*Physik. Zeitschr.*, 27, 1st November, 1926, pp. 659-680.)

The first device consists in connecting the vessel to be exhausted to the trunk tube of the pump by means of a narrow tube and sealing off close to the trunk, thus avoiding most of the gas set free from the heated surface of the glass getting into the vessel.

The second improvement refers to ground glass joints and taps in which the seal is effected without mercury or grease. The inner cone or plug is of metal and the outer surface of the outer cone or barrel respectively is coated with metal, and an electromotive force is applied between the two metal surfaces which draws them together.

THERMAL AGITATION OF ELECTRICITY IN CONDUCTORS.—J. Johnson. (*Nature*, 119, 8th January, 1927, pp. 50-51.)

Ordinary electric conductors are sources of spontaneous fluctuations of voltage which can be measured with sufficiently sensitive instruments. This property of conductors appears to be the result of thermal agitation of the electric charges in the material of the conductor. The effect has been observed and measured for various conductors, in the form of resistance units, by means of a vacuum tube amplifier terminated in a thermocouple. It manifests itself as a part of the phenomenon which is commonly called "tube noise." It is here shown that for the technique of amplification the effect means that the limit to the smallness of voltage which can be usefully amplified is often set, not by the vacuum tube, but by the very matter of which electrical circuits are built.

DEMONSTRATION OF SELENIUM CELLS.—H. Thirring. (*Phys. Soc. Proc.*, 39, 1, December, 1926, p. 97.)

Among the deficiencies naturally inherent in selenium cells are :—

1. The resistance is not a linear function of the intensity of illumination.
2. It has a temperature coefficient.
3. The reaction to light is not instantaneous.

The cells, therefore, have to be used in an arrangement which compensates as far as possible these deficiencies for the given purpose. Experiments were shown illustrating some of these arrangements.

THE AURORAL GREEN LINE 5577. (*Nature*, 119, 29th January, 1927, p. 162.)

A letter from Dr. Keys of McGill University, Montreal, describing evidence for the fact that the auroral green line is primarily due to oxygen, thus confirming the recent work of Prof. McLennan and his co-workers.

A DETERMINATION OF THE DIELECTRIC CONSTANT OF AIR BY A DISCHARGE METHOD.—A. Carman and K. Hubbard. (*Physical Review*, 29, January, 1927, p. 217.)

Abstract of a paper presented at the Chicago meeting of the American Physical Society, November, 1926.

A value of 1.000594 was found for the dielectric constant of air at 0°C. and 760 mm. Hg. pressure.

KATHODENZERSTÄUBUNGSPROBLEME (Problems of cathode sputtering).—A. v. Hippel. (*Annalen der Physik*, 81, 1926, pp. 1043-1075.)

A previous paper (*Ann. d. Phys.*, 80, 672) described a new method for investigating cathode sputtering and showed that sputtered metal particles consist very largely of uncharged atoms. The present paper deals with the theory of cathode sputtering.

KATHODENZERSTÄUBUNGSPROBLEME (Problems of cathode sputtering).—E. Blechschmidt. (*Annalen der Physik*, 81, 1926, pp. 999-1042.)

A paper dealing with the dependence of cathode sputtering on the working conditions, with a plate showing photographs of cathodes after sputtering.

SECONDARY ELECTRON EMISSION PRODUCED BY POSITIVE CAESIUM IONS.—J. Hyatt.

SECONDARY ELECTRON EMISSION FROM MOLYBDENUM.—A. Hull and J. Hyatt.

THE DISTRIBUTION OF ENERGY AMONG ELECTRONS REBOUNDING FROM HELIUM ATOMS.—A. Hughes and L. Jones.

(*Physical Review*, 29, January, 1927, p. 214.)

Abstracts of papers presented at the Chicago meeting of the American Physical Society November, 1926.

MISCELLANEOUS.

RADIO-TELEGRAPHY AND RADIO-TELEPHONY.—L. B. Turner. (*Journ. Inst. Elect. Engineers*, 65, January, 1927, pp. 131-136.)

A review of progress. Reprints (price 2s. 6d. each) are obtainable from the Secretary of the Institution.

DIE BETRIEBS-ZENTRALE DER TRANSRADIO A.-G. FÜR DRAHTLOSEN ÜBERSEE-VERKEHR (Headquarters of the joint-stock company Transradio for wireless communication overseas).—E. Quäck. (*Zeitschr. f. Hochfrequenz.*, 28, pp. 162-167, November, 1926.)

Detailed description of the Transradio Central Office in Berlin, which was completely remodelled in 1925. A plan of the building is shown and photographs of the different rooms for sending and receiving. This company owns the high power stations Nauen and Eilvese, with the receiving stations Geltow and Westerland a. Sylt, which are in regular communication with New York (Radio Corporation of America), Buenos Aires (Transradio Internacional Compania Radiotelegrafica Argentina), Rio de Janeiro (Companhia Radiotelegraphica Brazileira), Abu Zabal (British Government), Malabar (Netherlands Colonial Government), and also in one-way communication with China and Japan.

POLAND—RADIO COMMUNICATION. (*Electrical Review*, 99, 24th December, 1926, p. 1042.)

For communication with foreign countries the Post Office is in possession of four stations : the transatlantic station, built by the Radio Corporation of America, the transmitter comprising two 300kW alternators which can work in parallel on a very good elaborated aerial ; arc transmitters at Cracow and Poznan which only permit of hand-speed working ; and a French alternator station of approx. 6kW at Grudziadz, used mostly for communication with France.

The last three stations are "extremely inefficient," and are not equipped with modern receivers, and the running expenses of the first station are so high, for the small number of words available for transmission, that special credits have to be voted by the Diet to cover the losses. Only a small part of correspondence which could be transmitted from and received in Poland is going by wireless.

FRANCE—CONTROL PLAN. (*Electrical Review*, 99, 24th December, 1926, p. 1042.)

M. Bokanowski, Minister of Commerce, who recently described the conditions under which French broadcasting is carried on as "anarchic," is stated to have submitted a scheme of control to the Post Office Department. In the *Review* of 7th January, p. 21, it is announced that broadcasting now becomes the prerogative of the State, which will assume possession of all transmitting stations in five years' time, and that meanwhile broadcasting will be controlled by a mixed committee of Government officials, authors, musicians and lecturers, who will supervise operation carried out by authorised private enterprise.

PORTUGAL—NEW WIRELESS TELEGRAPH SERVICE. (*Electrical Review*, 99, 24th December, 1926, p. 1042.)

A direct high-speed wireless telegraph service between England and Portugal was opened on 15th December. It is the first of a number of wireless services which are being established by the Portuguese Marconi Company under a 40 years' concession granted by the Portuguese Government to Marconi's Wireless Telegraph Co., Ltd., to undertake the organisation of a complete wireless telegraph and telephone system to place Portugal in communication with her Colonies, the principal capitals of Europe, South America, and other countries. Stations are being built near Lisbon, in Cape Verde Islands, Madeira, the Azores, Mozambique, and Angola.

TELEVISION. (*Nature*, 119, 15th January, 1927, pp. 73-74.)

An article giving the writer's impressions of the lecture delivered by Mr. Baird on 6th January at the Physical and Optical Society's exhibition, stating that Mr. Baird did not add to the general knowledge by what he said and did on that occasion. In a letter to *Nature* of 29th January, Mr. Baird replies to statements and criticisms contained in the article, the Editor adding a footnote that this further information is precisely the kind which physicists were waiting for.

PREFERRED NUMBERS.—L. Hazeltine. (*Proc. Inst. Radio Engineers*, 14, December, 1926, pp 785-787.)

The Institute of Radio Engineers is taking part in the study of Preferred Numbers and their application, and would welcome comments by radio engineers.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto - Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPRECOJ DE CIRKVITOJ.

KELKAJ NOVAJ DIAGRAMOJ DE BOBENAJ IMPEDANCOJ.—W. A. Barclay.

La artikolo traktas pri la aplikado de la enliniiga principo al la kalkulado de reaktancaj kaj impedancaj valoroj en alternkurentaj cirkvitoj. Kelkaj utilaj ekzemploj estas bone ilustritaj per serio de diagramoj montrantaj la konstruadon por induktaj kaj kapacitaj reaktancoj, resonancon, k.t.p.

SIMPLAJ RESONANCAJ KURVOJ KAJ ILIA MODIFO PER VALVAJ CIRKVITOJ.—Prof. E. Mallett.

La aŭtoro priskribas vektoran traktadon de simplaj resonancaj kurvoj. Pere de la traktado, la resonanca kurvo estas antaŭdirebla en okazoj, kie estas nur unu agordita cirkvito, kiu povas esti kunigita al valvo kun aŭ sen reakcio. Alternative, per resonanca kurvo eksperimente obtenita per variigo de la frekvenco, la efektiva velkada faktoro de la cirkvito estas trovebla. La kondiĉoj por la konservado de osciladoj per valvo estas ankaŭ kalkuleblaj.

La traktado estas dividita laŭjene :—

1. Seria impedanco—resonancaj kurvoj kaj cirkloj—cirkla kaj rektlinia konstruado por trovi velkadan faktoron.

2. Paralela resonanco—agordita anoda cirkvito—kondiĉoj por oscilado—anoda spilo.

3. Oscila cirkvito konektita al krado—kondiĉoj por oscilado.

RICEVADO.

LA AGADO DE AMPLIFIKATOROJ—P. K. Turner.

Unue la aŭtoro ilustras kaj diskutas kurvon por trivalva aparato mezkvalita, la frekvencaj abscisoj estante laŭ oktavoj de tonalteco, dum la ordinatoj estas amplifitaj. Oni sugestas, ke pro tio, ke la diferenco de impreso farita ĉe l'orelo per du

nesamaj volumoj de sono estas afero de ilia proporcio, pli ol iliaj absolutaj valoroj, la ordinatoj devus ankaŭ esti efektive logaritmaj, ekz., esprimitaj laŭ " Sendaj Unuoj," kiel je la telefona praktikado. Tiel taksite, la agadon de la amplifikatoro aludita, oni montras plibonan ol unue sugestitan. Similaj kurvoj estas poste donitaj por du aliaj amplifikatoroj, unu, Burndept Ethophone III., Marko IV., kaj la alia, laboreje konstruita rezistance kuplita aparato, ĉiu kun tri valvoj. La unua donas skalon de 70 ĝis 4,000 cikloj kun 25-procenta falo, kaj 30 ĝis 7,000 cikloj kun 50-procenta falo, dum la lasta donas 30 ĝis 7,000 ciklojn kun nur 25-procenta falo.

La metodo de mezurado estas ilustrita kaj diskutita.

ALTA-TENSIO KAJ MALALTA-TENSIO PERE DE 250-VOLTA KONTINUKURENTA PROVIZO.—A. Robertson.

La aŭtoro priskribas kaj ilustras la utiligadon de elektraj ĉeftuboj de 250-volta Kontinua Kurento por filamenta varmigado kaj alta tensio. Por unuvalva aparato oni montras la ĉeftubojn uzitajn senpere por filamenta provizado, dum por triyalva aparato, varianta baterio estas ilustrita. Sokaj kaj glatigaj aranĝoj estas ankaŭ diskutitaj, kaj nova speco de transformatoro estas priskribita, utiliganta la ŝanĝon de kurento ĉe la pozitiva kaj negativa membroj de la filamento kiam la anoda cirkvito estas energiita.

SUBGRADA EKIPAĴO KAJ MATERIALOJ.

LA DESEGNO DE HETERODINA TIPO DE MALALT-FREKVENCA GENERATORO.—H. L. Kirke.

La generatoro priskribita estas de la tipo, kiu uzas la radio-frekvencajn oscilatorojn por produkti aŭdeblan baton, kiun oni povas variigi por ampleksi la bezonitan skalon de aŭd-frekvenca elmeto.

La du oscilatoroj funkcias je ĉirkaŭ 4,000 metroj, unu estante variebla, kaj la alia fiksita laŭ frekvenco. Iliaj elmetoj estas kondukitaj al rektifikatoro, kaj la rezultanta malalta frekvenco estas pasigita tra taŭga amplifikatoro. La amplifikatoro estas kuplita rezistec-kapacite, kun altfrekvencaj ŝokbobenoj kaj paralelaj kondensatoroj en ĉiu kupla ŝtupo, inter la kupla kondensatoro kaj krado. La kontrolo de volumo estas donita de potenciometroj ĉe du el la ŝtupoj.

La generatoro provizas maksimuman elmeton de 0.5 vato, kun frekvenca skalo de 50 ĝis 10,000 cikloj. La elmeto estas konstanta super la tuta frekvenca skalo, kaj donas ondan formon proksimiĝantan je sinusa ondo.

Retroglitebla unuo estas utiligita por mezuri la elmeton.

En la artikolo, la teorio de la generatoro estas diskutita, kaj la desegno de la oscilatoroj kaj amplifikatoro priskribita kaj ilustrita per diagramoj kaj ilustraĵoj. Oni donas ankaŭ notojn pri normigado, konstanteco de frekvenco, kaj ponta metodo de frekvenca mezurado.

LA AKUSTIKAJ PROBLEMOJ DE MIKROFONOJ KAJ LAŬTPAROLILOJ.

Raporto pri neformala diskutado pri la ĉisupra temo, tenita ĉe la monata kunveno de la Senfadena Sekcio, Institucio de Elektraj Inĝenieroj, je 5a Januaro, 1927a.

La diskutadon malfermis S-ro. G. H. Nash, kaj daŭrigis S-roj. B. S. Cohen, P. P. Eckersley, C. F. Phillips, kaj aliaj.

DIVERSAĴOJ.

MATEMATIKOJ POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj.

La nuna parto traktas pri la kontinueco de Funkcioj kaj Limoj, la Funkcio

$$y = 10^{\frac{1}{x-1}} + 1$$

estante pritraktita detale laŭ ambaŭ vidpunktoj.

AFEROJ SENFADENE INTERESAJ ĈE LA EKSPOZICIO DE LA FIZIKA SOCIETO.

Oni donas mallongan raporton pri aferoj interesaj laŭ senfadena vidpunkto ĉe la Deksepa Ĉiujara Ekspozicio de Aparataro, tenita de la Fizika Societo kaj Optika Societo ĉe la Imperia Kolegio, South Kensington, Londono, je la 4a, 5a, kaj 6a Januaro 1927a.

LIBRO-RECENZOJ.

Jen grava recenzo (de D-ro. D. W. Dye) pri " Radio-Frekvencaj Mezuraj : Manlibro por la Laborejo kaj Lernolibro por Altgradaj Studentoj," de E. B. Moullin, M.A.

Kvar aliaj verkoj estas ankaŭ recenzitaj de Prof. G. W. O. Howe.

RESUMOJ KAJ ALUDOJ.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato) kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

ERRATUM.

RADIO FREQUENCY MEASUREMENTS.—The expression on page 109, col. 1, of the February issue, should read

$$\frac{\sqrt{I^2_{res} - I^2}}{I^2}$$

instead of as there shown.

Correspondence.

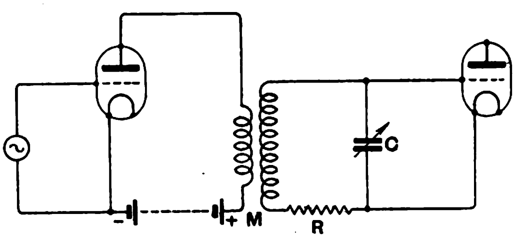
Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

Plate-Current, Plate-Voltage Characteristics.

To the Editor, E.W. & W.E.

SIR,—Mr. Holt Smith disagrees with the statement in my article that " For amplifiers using tuned circuits, maximum amplification occurs when the output power is a maximum for a given amplitude of grid voltage," and goes on to state that if the resistance of the tuned circuit is zero, then we get maximum amplification with minimum output.

Mr. Holt Smith apparently has not noticed the typical diagram I gave for a tuned circuit amplifier, and which I reproduce here. It is only with such a type that the effective load of the tuned circuit in the plate circuit can be varied efficiently.



If R=series resistance of tuned circuit.
M=mutual inductance between grid and plate coil.
$\omega=2\pi\times$ frequency in use.

Then with the grid circuit in tune the resistance this circuit provides in the plate circuit, through the mutual inductance M, is $\frac{M^2\omega^2}{R}$ and can be made equal to the A.C. plate resistance, thus ensuring maximum power output for a given input. This power is delivered to the tuned circuit, and will obviously give the maximum voltage across it.

If the resistance of the tuned circuit is reduced to zero as Mr. Holt Smith suggests, theoretically an infinite step-up could be obtained. In practice, even with the lowest resistance coil, we have to be content with a much more modest value.

Much could be written from the practical point of view as regards the step-up obtainable at various wavelengths, but enough has been said to defend the original statement. The article was on plate-current, plate voltage curves, and circuits could only be touched on very lightly if the article was to be kept to a reasonable length. E. GREEN.

That Audio Transformer Problem.

To the Editor, E.W. & W.E.

SIR,—The problem of the audio-frequency transformer is one which concerns all of us in a greater or less degree, and I trust that this, I fear rather lengthy contribution, mainly in answer to the letters of your correspondents Messrs. Albert Hall and C. Holt Smith appearing in your January issue, will be acceptable in full.

The contents of my letter in your November issue have not apparently been properly appreciated. As stated, it was not possible to give a complete explanation, and the letter was largely only a statement of the case. So far as it goes, its contents are quite correct.

Now, sir, I have, I hope, this opportunity of making matters somewhat clearer.

When variations and maxima of quantities of any kind are under consideration it is most necessary to keep clearly in mind the postulated basis over which these variations are supposed to occur. Thus, Mr. Albert Hall has not in his letter—see particularly his unfortunate last sentence—understood that the general principle concerning primary impedance in relation to that of the valve was as stated, on the basis of a given frequency. The figures which he quotes, far from giving me a " problem to solve," are, so far as they go, in agreement with the principles to which I refer below.

The basic principles of this problem, inclusive generally of *all* effects occurring in transformers, are :—

1. For varying degrees of primary winding fineness in a given winding space (excluding capacity effects for the moment only) the maximum inductive voltage per turn *for any one frequency*, and therefore the maximum voltage of a given secondary winding, occurs when the winding fineness is such that the impedance is (approximately for iron) *equal* to that of the valve.

That is certainly true, and as indicated by Mr. Holt Smith, readily capable of proof when winding self-capacity may be neglected.

It is also true of the combined impedance in the most important case and true in a modified form in another (constant parallel capacity) when self and/or additional parallel capacity is taken into account, but to this I shall again refer when discussing the letter from Mr. Holt Smith.

Hysteresis and eddy current effects are included in these statements.

2. The *magnitude of this maximum* effect increases with the frequency though in the case of constant parallel capacity it ultimately decreases again due to the required value of the tuning capacity becoming reduced, as a result of hysteresis and eddy currents.

3. With any *given windings* the amplification, *i.e.*, inductive voltage per turn, increases with the frequency up to a point, after which it falls mainly due to capacity effects, but at any one frequency for which the primary impedance, with or without parallel capacity, is materially greater than that of the valve, the amplification at that frequency could be increased by reducing the impedance of the winding or combination to the region of equality, provided in the latter case the change is effected by reducing the impedance of the winding, which is the same as saying that the combination does not at any time give a condenser effect.

4. With a given secondary of highest number of turns reasonably possible, maximum volt amplification occurs when the effective primary, *i.e.*, the

primary inclusive of the capacity effects of secondary, eddy currents and hysteresis, is *tuned* by self plus added capacity to the given frequency, the fineness of the primary winding being such that the *impedance of the combination* is *equal* to that of the valve.

It is not possible for me to consider here Mr. Hall's figures in detail, but it will readily be seen that they do not contradict these principles.

In reference to Mr. Hall's second paragraph and to the last sentence of his third, I trust that after perusal of this letter he will himself be better able to understand this matter. The remainder of his third paragraph with " release " substituted for " produce " is agreed to, but is surely too elementary to have been included in this discussion.

Mr. Holt Smith's observations on this problem, though not incorrect so far as they go, are to some extent misleading. Naturally, if we could have a transformer with a constant ratio and with no capacity effects, we should want the highest possible impedance ; in fact, it is only the case of the choke, with its gradual approach to an asymptotic maximum. But then he appears to agree that that is not a practical case.

The transformer problem is fundamentally different. We have a secondary of the maximum number of turns which is practically possible, which has resistance and self-capacity. We have so to excite the core as to obtain at the given frequency maximum induced effect in that secondary. It is a case of producing maximum volt-amperes in the primary winding space at our disposal, not maximum volts, and it is the $\mu \times m$ of the valve which counts, not the μ alone.

His point, which is " at variance with my rule," is correct. But I did not lay down a rule ; I stated that the basic principle of equality of primary and valve impedance for maximum amplificaton was not incorrect, and that that of the utmost possible primary impedance was, which is true. If Mr. Holt Smith will apply pen to paper once again, he will discover that the absolute maximum effect in his more practical case occurs when the primary is tuned *and* of equal impedance with the valve at the same time. For given windings, the optimum is obtained when the primary is *tuned* by parallel capacity (total current in phase). Then, for the tuned condition and varying primary, optimum is again obtained when impedance of combination *equals* that of valve. So he will see that the reason he increases the amplification by increasing the impedance away from the valve is that he is approaching the tuned condition from the wrong side, so to speak. Nevertheless the principle of equality is correct for the absolute maximum.

If we take, as he has done, the case of a constant capacity, it is true that the optimum does not occur when there is equality, but there is still a true (not asymptotic) maximum which occurs in this case when the impedance of the combination bears a definite ratio—not very far removed from unity for small capacities and/or frequencies—to that of the valve.

This principle of equality of primary impedance and valve for maximum amplification at a given frequency is thus, after all, a general principle and *not* an error. It need not be taken with a " pinch of salt," and Mr. Hall is simply wrong when he says that it is " an erroneous idea." On the other hand, the notion held by Mr. I. A. J. Duff, and which has been thrust on the radio public as the " truth " in certain recent advertisements from another source, that the primary should be of the utmost possible impedance, is definitely erroneous, and is one which, carried out practically to its technically, as distinct from commercially, possible extent, leads to an incorrect transformer.

The equality principle is correct for the absolute maximum in all cases, inclusive of *all* effects, but because we have to apply it at lower and lower frequencies, in order to bring in lower and lower notes, the erroneous idea has arisen that we require intrinsically the highest possible primary inductance, which is not the case.

Nevertheless, as I have amply proved experimentally, it is true that we want higher values than are found in many transformers.

E. Fowler Clark,
B.Sc., B.A., A.M.I.E.E.

The Performance of Amplifiers.

To the Editor, E.W. & W.E.

Sir,—I have read with interest your editorial note in the issue for February, referring to my short article in the same issue. In the last paragraph of this editorial note you express an objection to the procedure adopted during the tests, and (although I may be unduly sensitive) this paragraph gave me the impression that you felt that perhaps this method had been deliberately adopted to favour some particular point of view ; you refer to it as a " peculiar procedure," and go on to say that the tests " would have been more convincing " if certain other measures had been adopted.

Perhaps you will allow me to explain that these tests were undertaken primarily to measure the performance of the audio-frequency side of the sets in question. I quite agree with the remark that tests made on a radio-frequency voltage modulated with a pure sine wave would have been more convincing, but I have no hope of making really satisfactory tests on these lines for some months to come : I find it is extremely difficult, with the apparatus available to me, to devise any method by which I can modulate an R.F. oscillator, in which the output of such oscillator is exactly known, and in which, further, the radio-frequency amplitude is modulated in a strictly linear manner. It is obvious that if this last requirement is not fulfilled, the envelope of the radio-frequency output will not be a pure sine wave. However, perhaps later on I may be able to get over this difficulty.

In any case, tests so conducted introduce several other factors into the performance of the receiver, notably the favouring of low frequencies, caused by the selectivity of the radio-frequency side of the set.

Granted that it was necessary to feed the set with audio-frequency voltage, it would, of course, have been possible to deal with the set only as from the grid of the first L.F. valve. This, however, would have failed to show up the frequency response characteristic of the coupling between the detector and the first L.F. valve. As this is an essential part of the L.F. side of the set, I considered it quite necessary to include it. It would, of course, have

been quite unjustifiable to remove the detector valve and feed in the audio-frequency E.M.F. in place of it, as this would have changed the response characteristic of the coupling in question. It therefore seemed to me obvious that the L.F. energy should be fed in at the grid of the detector valve, which is in actual fact the closest approximation possible in the circumstances to the normal action of the set. Had I left the valve with its grid positive, it would, of course, have set up such waveform distortion that the set would not have been amplifying a pure sine wave. It was therefore necessary to make the grid slightly negative. The grid condenser and leak were not removed, but of course as the grid is maintained negative the leak carries no current. The net effect was to diminish slightly the anode current of this valve, though not so much as would be expected, for although the grid had been previously connected to filament positive, the drop across the leak brought the grid very nearly to zero potential. An investigation was made to see whether there was any change in the anode A.C. resistance of the valve, due to working on a different part of the characteristic, but this was found to be negligible.

I regret very much that I did not go into this point more fully in the article itself, but, frankly, it appeared to me to be such an obvious matter as to need no explanation.

With regard to the last few lines of the editorial note, in which you are interested in the possible cause of the bad response curve of the set shown in Fig. 1, this was simply due to the fact that the set had two transformer coupled stages, in which the transformers were not very well designed, and, moreover were not particularly well suited to the valves specified. If you take the square root of the ordinates in Fig. 1, or half the ordinates in Fig. 2, you will get a rough approximation to the curve of one of these transformers, and you will at once perceive that it is typical of a transformer of indifferent design.

Blackheath, S.E.3. P. K. TURNER.

Quartz Crystal Stabilisation of Transmitters.

To the Editor, E.W. & W.E.

SIR,—In my article on quartz crystal-controlled transmitters in the December issue, the tuned-plate, tuned-grid circuit is used throughout. This circuit oscillates without magnetic coupling due to the feed-back through the valve capacity. I have recently found that with some valves the feed-back is so great that it causes over excitation of the grid. As the synchronising effect required is inversely proportional to the grid excitation it is evident that the range of synchronisation can be considerably increased in this case by reducing the grid excitation. This can be simply effected by partial neutralisation (by taking a tap from a point below the low potential side of the plate inductance, through a condenser to the grid of the valve in the usual manner). The adjustment is not critical as complete neutralisation is not desired. The efficiency of the circuit is also increased by this procedure.

N.W.7. C. W. GOYDER, G2SZ.

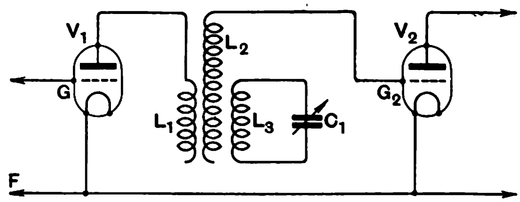
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each.

A HIGH FREQUENCY AMPLIFIER.

(*Application date, 12th August*, 1925. *No.* 261,088.)

A form of intervalve coupling for high frequency amplification is described in the above British Patent by Radio Patents Corporation and W. Dubilier, one arrangement of the invention being shown in the accompanying illustration. Signal voltages are applied between the grid G and filament F of the valve V_1, the anode circuit of which contains an inductance L_1, comprising the primary coil of a high frequency transformer. One end of the coil L_1 is connected to the anode, of course, while the other end is connected to the high tension battery, which is not shown. The secondary winding comprises an inductance L_2 having a very much larger number of turns than the inductance L_1, and is connected between the grid G_2 of the valve V_2, and the common filament lead F of the grid bias battery. Coupled to L_1 and L_2 is another inductance L_3, tuned by a condenser C_1, the oscillatory circuit L_3 C_1 being in resonance with the frequency of the oscillations to be amplified. The specification states that this arrangement results in an amplification which is sometimes 50 per cent. greater than the more normal form of high frequency transformer. A similar arrangement can be applied to an aerial circuit, where the inductance L_1 comprises the aerial tuning coil,



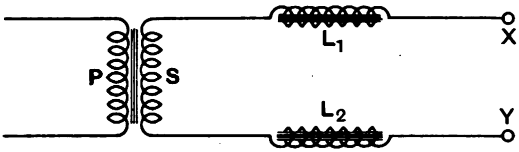
and the inductance L_2 is connected to the grid-filament circuit of the first valve, the closed circuit L_3 C_1 being coupled to the inductance L_2 as before.

ELIMINATING HUM.

(*Application date, 27th January*, 1926. *No.* 262,979.

Most methods of eliminating ripple in rectified A.C. supply for receiving sets consists in introducing a filter system into the rectified power supply which is applied to the valve. A method is claimed by

W. E. H. Humphrys in the above British Patent, which consists in introducing chokes into the output of the receiver. A convenient method of carrying this into effect is shown in the accompanying illustration, where an output transformer comprising a primary winding P and a secondary winding S

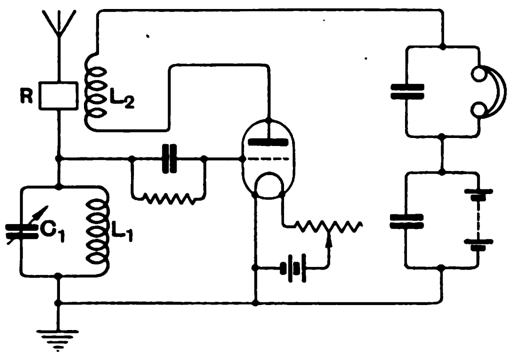


is connected in the anode circuit of the last valve. The telephones or loud speakers are connected at XY, *i.e.*, across the secondary of the transformer, but in series with the two leads from the secondary are two chokes L_1 and L_2, which offer considerable impedance to currents of frequencies of the orders of those due to the ripple.

CONSTANT REACTION CONTROL.

(*Application date, 6th October*, 1925. *No.* 263,560.)

A method of obtaining constant reaction control is described by M. A. Robinson in the above British Patent. The accompanying illustration should make the invention quite clear, the main feature being the inclusion of a resistance in the aerial circuit. A single valve receiver is shown in the diagram, the input comprising a tuned circuit L_1C_1 connected between the grid and the filament, the usual condenser and leak being included for rectification, while a reaction coil L_2 is coupled in fixed relationship with the inductance L_1, the telephones and high tension battery being connected

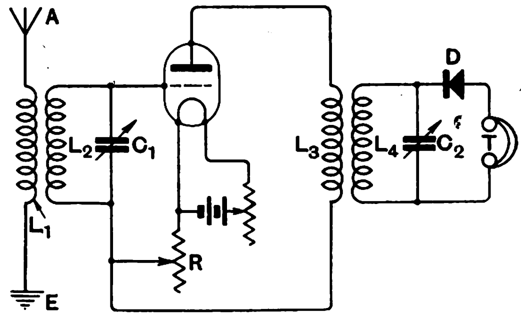


in the normal manner. It is well known that if the aerial is connected to the grid the amount of regeneration existent in the system will vary with the capacity existing between the grid and the fi a-ment, *i.e.*, wi h the position of the tuning condenser. The aerial system, which one can regard as a combination of inductance and capacity, and, of course, resistance, materially affects the tuned circuit L_1C_1. If, however, a resistance such as that shown at R is included between the aerial and the grid or high potential end of the input circuit, its effect on the tuned circuit L_1C_1 will not be so great. It is stated in the invention that by suitably adjusting this resistance it is possible to obtain a fairly constant degree of reaction or regeneration throughout the whole tuning range irrespective of the position of the tuning condenser C_1. Whether this effect is fulfilled or not is very materially influenced by the constants of the remainder of the circuit, this being pointed out in the specification.

STABILISING VALVE AMPLIFIERS.

(*Convention date* (*U.S.A.*), 13*th October*, 1924. *No.* 241,185.)

A method of stabilising valve amplifiers depending upon coupling back potentials produced across a resistance in the anode circuit into the grid circuit is described in the above British Patent by R. E.



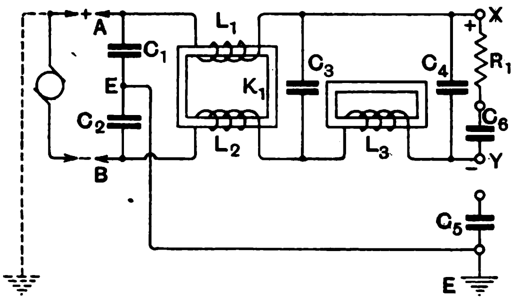
Manufacturing Co. and Boyd Phelps. The basic idea of the invention can be gathered by referring to the accompanying diagram, which shows a valve amplifier followed by a crystal rectifier. Here the aerial circuit comprises an aerial A, earth connection E, and an inductance L_1 coupled to an inductance L_2 tuned by a variable condenser C_1. The anode circuit contains a high frequency transformer L_3 L_4, the secondary of which is tuned by a condenser C_2. The amplified potentials produced across the secondary of the transformer are rectified by a crystal detector D in series with the telephones T. The usual filament and anode batteries are shown. Instead of connecting the negative terminal of the high tension battery and the lower end of the grid circuit directly to the filament, connection is made through a resistance R. Since the resistance R comprises part of the anode circuit, a portion of the potentials produced in this circuit will naturally occur across the resistance, but since this resistance is also in the grid circuit the potentials produced across it will be transferred to the grid of the valve. But as the anode and grid potentials are substantially 180 degrees out of phase, the potential which is applied to the grid from the anode circuit will oppose that applied to the grid from the signal voltage, or whatever may be exciting the valve. Thus it will be seen that if there is a tendency for continuous oscillations to be sustained by the valve acting as a generator—due, perhaps, to stray magnetic or capacitative coupling—by suitably adjusting the resistance value sufficient opposition phase voltage can be introduced into the grid circuit to cause cessation of oscillation. It must be remembered, of course, that a valve connected in this manner, while being stable in operation, tends to lower the amplification, since

the amplification of all voltages applied to the grid of the valve will be somewhat diminished. The specification is detailed, and contains several multi-valve circuits embodying this principle.

SMOOTHING DIRECT CURRENT SUPPLY.

(*Convention date* (*U.S.A.*), *24th October*, 1924. *No.* 241,944.)

Some very broad claims are made in the above British Patent, granted to the Dubilier Condenser Company (1925), Limited, and H. W. Houck, for an arrangement of smoothing circuits in combination with a direct current supply for receiving sets. The smoothing circuit is shown in the accompanying illustration, and should be readily understood. The direct current mains are introduced at A and B, which are positive and negative respectively. Across the mains are two condensers C_1 and C_2 a centre point earth being taken at E. The two mains are then passed through chokes L_1 and L_2 arranged on a common core K_1, the two chokes then being shunted by a third condenser C_3, another choke L_3 being included in the negative lead, and another condenser C_4 being placed on the other side. The earth connection to the set is taken through a safety

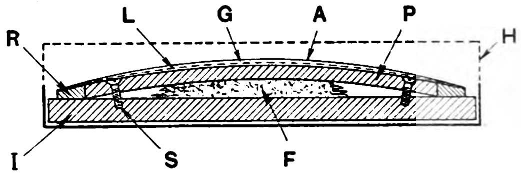


condenser C_5. The main supply is taken across X and Y, these representing respectively the positive and negative terminals of the smoothed output. A lower voltage for working the detector valve of the receiving system is derived from a series resistance R_1 and a by-pass condenser C_3. The filter system briefly described is a double π filter with a centre point earth to the integrating condenser, and chokes in both limbs of the first π and a choke in one limb of the second π.

A CAPACITY MICROPHONE.

(*Application date*, *21st December*, 1925. *No.* 263,300.)

A very interesting form of condenser microphone is described by P. G. A. H. Voight in the above British Patent Specification, the accompanying illustration showing one form of the microphone. The two electrodes consist of a heavy rigid plate and a very light moving foil area. The heavy electrode consists of a metal plate P which is damped with felt or similar material F, the plate being screwed to another insulating plate I by screws S. Alternatively, it may consist of some non-resonant substance coated with a metallic film if the substance happens to be non-conducting. The other electrode consists of very thin aluminium foil A, about 1/2000 inch thick. This is separated from the back electrode P by a layer of air G which acts as a cushion. In order to prevent any short circuit occurring between the two a layer of silk L is interposed. The specification states that the mass of the aluminium foil, together with the resiliency of the gas layer, produces a resonant



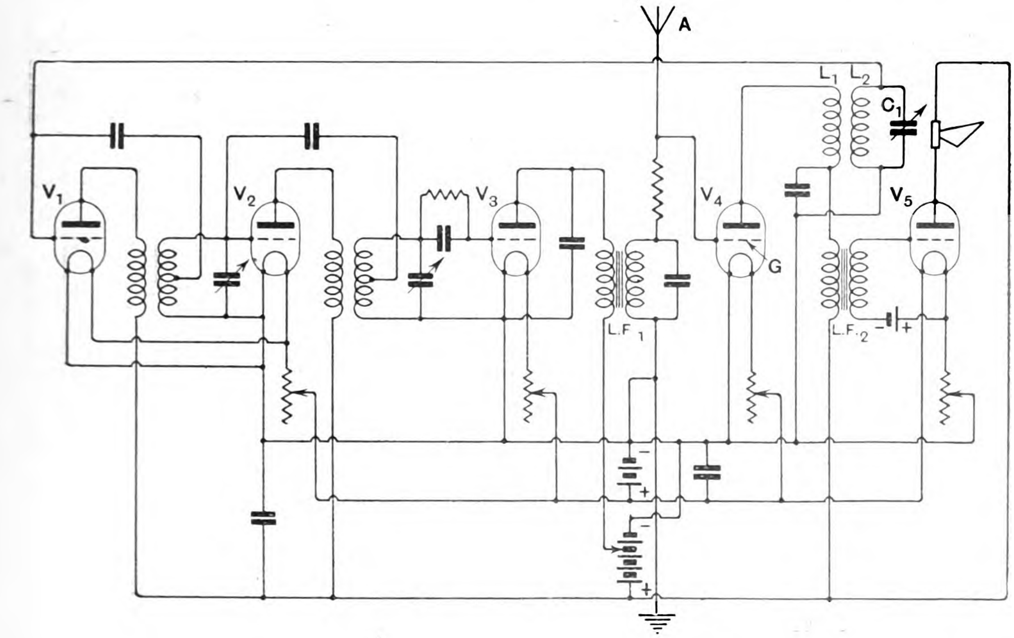
system, but with foil of the thickness stated, and an air cushion of about 1/32 inch the natural frequency is of the order of 16,000 cycles per second. Another interesting point is that as the air cushion is likely to be of varying thickness the diaphragm will not be resonant as a whole, but tend to have various natural frequencies at various parts of the surface. Referring again to the illustration, in one modification of the invention the foil is stuck to a ring R which, in turn, is fixed to the insulating plate I. In order to protect the microphone from stray capacity effects a metal screen is used, as at H. Another modification of the invention lies in the use of two foil areas instead of one foil and a rigid back plate. The specification, while short, is exceedingly detailed, and contains a great amount of useful information and minor points regarding the successful operation of the microphone. For example, it is stated that the air must be perfectly dry to prevent leakage, and means can be provided for sealing the air into the microphone, or else allowing it to be free and providing calcium chloride for absorbing the moisture. It is stated that silent working can frequently be obtained by connecting a battery between the electrodes. It is stated that this probably causes the moisture to decompose, thus restoring the insulation between the two electrodes.

AN INTERESTING RECEIVER.

(*Application date* (*U.S.A.*), *26th May*, 1925. *No.* 252,691.)

A rather interesting receiver is described in the above British Patent by the Hazeltine Corporation and W. A. MacDonald. The invention broadly consists in using a multi-valve radio frequency amplifier with an untuned aerial circuit, the aerial being connected to the grid of the valve, an untuned circuit being connected to the input of this valve. In the accompanying illustration an aerial A is connected to the grid G of the valve V_4, the anode circuit of which contains the primary L_1 of a transformer L_1 L_2, the secondary being tuned by a condenser C_1. This secondary is connected to the grid of the first ordinary amplifying valve V_1. The valve V_2 acts as another radio frequency amplifier, and is coupled to the valve V_1 by means of a neutralised centre-tapped secondary transformer. A similar transformer is connected to the output of

the valve V_2, and the amplified oscillations occurring across the secondary of this are rectified by the valve V_3. As this part of the circuit is entirely normal it will not be described in detail. The output of the detector valve contains a low frequency transformer LF_1. The secondary of this transformer is connected to earth and the grid of the valve V_4, which also acts as a low frequency amplifier, the low frequency output of which is coupled by another transformer LF_2 to the grid filament circuit of the last valve V_5 which operates the loud-speaker. In order to prevent high frequency oscillations being short-circuited to earth through the shunt capacity across the first low frequency transformer a resistance R is inserted as shown, *i.e.*, in series with the grid connection to the special dual amplifying valve V_4. This resistance R will not materially affect the magnitude of the low frequency voltages applied to the grid of the valve V_4, but will effectively prevent the transference of any high frequency currents from the aerial. It is claimed that this circuit while oscillating will radiate only to a very small extent, because the high frequency oscillations can only pass to the aerial through the inter-electrode capacity of the valve V_4, and, moreover, since the aerial circuit is substantially aperiodic it will not tend to radiate very strongly.

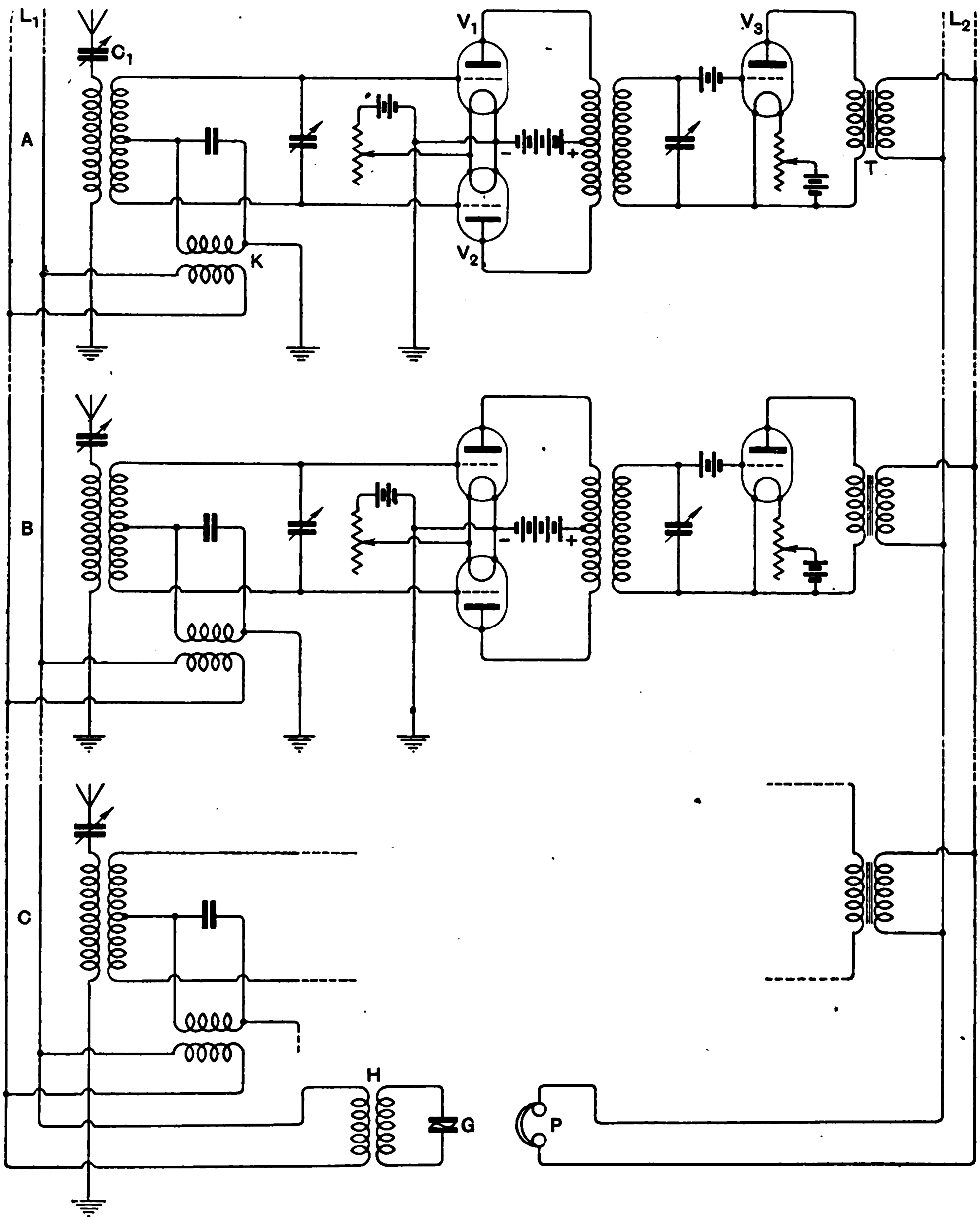


ELIMINATING FADING.

(*Convention date* (*U.S.A.*), 19*th June*, 1925. *No.* 253,934.)

Marconi's Wireless Telegraph Company Limited, and H. O. Peterson also describe in the above British Patent a method of eliminating the effect of fading by using a number of receiving stations arranged along a line joining the main desired point of reception and the transmitter. It is pointed out that at various distances along this line the received signal voltages from the earth wave and the reflected wave will be of varying magnitude and varying phase. The invention consists in receiving signals from a number of stations and combining the whole in a common output circuit. One form of the invention is shown in the accompanying diagram. Three stations are shown at A, B, and C, the arrangement of the apparatus being identical in each case. The stations are connected by two lines L_1, and L_2. The arrangement of the system of the station A only will be described briefly, since the others are similar. The aerial circuit comprises a capacity C_1 and an inductance L_1. This is coupled to a modulating system of a known type, consisting of valves V_1 and V_2 and balanced input and output circuits, which will not be described in detail, since readers are no doubt familiar with this modulating system, it being similar to that used in side band transmission. The output from the valve arrangement V_1 and V_2 is transferred to a valve V_3, which acts as a detector, and is provided with a low frequency output transformer T, feeding the line L_2. A source of audio frequency, or radio frequency modulated at an audio frequency is shown at G, and feeds the line L_1 through a transformer H. The line L_1 is connected through a transformer K, the secondary of which is connected to earth and the mid point of the modulating system. Normally, when no signal voltages are being received by the aerial system the audio frequency component derived from the line L_1 will give rise to no audio frequency currents in the valve V_3, and therefore

no effect will be obtained in the line L_2 which feeds the telephones P. When, however, signal voltages arrive their effect is combined with the audio



frequency component fed from the line L_1, with the result that voltages are produced across the line L_2, and operate the telephones P. The same sequence of operations occurs with all stations feeding the line L_2, with the result that a fairly constant signal is obtained in the telephones P, which is derived from the various signal voltages as they occur along the line. The greater the number of stations used, which, of course must be suitably disposed, the more constant will be the reception.

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EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. APRIL, 1927. No. 43.

Editorials.

Effect of Natural Phenomena on Signal Strength.

SINCE the first transatlantic transmissions twenty-five years ago attempts have been made to correlate the fluctuations in the strength of the received signals with various natural phenomena. In addition to the position of the sun, the effect of which is beyond all doubt, the phases of the moon, the height of the barometer, the humidity, the temperature, the earth's magnetic field and sun spots have all been regarded as possible causes of fluctuation. Even if some correlation appears to exist between signal strength and any of these variables, it does not follow that that meteorological condition has any direct effect on the electromagnetic waves; they may both be due to some other cause. Dr. L. W. Austin has recently reported that, as the result of tests made at Washington on signals from stations between 100 and 200 miles away, he has come to the conclusion that whenever the temperature rises along the signal path there is a tendency for the strength of the signal to drop, and conversely a falling temperature tends to produce a stronger signal, although the temperature effects are often masked by other unknown influences. It must be remembered that these results were only obtained for ranges between 100 and 200 miles over which the temperature would be fairly uniform. Assuming that the correlation really exists and is not merely accidental it seems useless to try to find an explanation unless one knows what other meteorological changes are associated with a rise or fall of temperature and what effect these changes will have on the ionisation of the upper atmosphere. In case any enthusiastic amateur experimenter thinks of making similar observations we would point out that Dr. Austin's conclusions were based on two years' observations; to be of value the tests must cover a long period and the results must be carefully analysed before one can say whether any relation exists between the two phenomena. The same remarks apply to observations of the effect of other meteorological variables such as the phases of the moon.

Transmitter Frequency Control.

ONE of the problems of C.W. transmission has always been the maintenance of a constant frequency. Very ingenious and elaborate apparatus has been developed for enabling high frequency alternators to maintain a reasonable constancy of speed during transmission. With valve generators the frequency depends primarily on circuit conditions which can be maintained constant to a high degree of accuracy, but not to a sufficiently high degree to meet the ever increasing requirements of modern developments. It is not merely a question of maintaining the frequency constant but of maintaining it at a definite value. To make the frequency more definite than it

would be if controlled entirely by electrical constants, a lightly damped mechanical oscillatory system is employed to control the electrical oscillations. In some cases this is a tuning fork, in others it is a piezo-electric crystal. In either case the frequency can be maintained at a definite value to a high degree of accuracy, provided the mechanical oscillator is maintained at a constant temperature.

At the recent exhibition held by the Physical Society of London an ingenious device was shown in operation by Dr. Dye which opens up a further possibility in the control of frequency. A tuning fork which is adjusted as nearly as possible to 50 oscillations per second receives every second an impulse from a clock, the pendulum of which operates a contact and causes a momentary current to flow in the iron-cored coil which acts on the fork. Any slight departure of the fork from the phase corresponding to a frequency of exactly 50 oscillations per second is rectified every second by the impulse from the clock. If the oscillations over a period of several seconds are analysed the principal component will be found to have a frequency exactly 50 times that of the clock impulses.

It is not easy to foresee the effect of trying to use such a device to control the frequency of a transmitting station, but the possibility is suggested of controlling the frequency, say, of the Rugby Station from a clock in Greenwich Observatory.

Variable Air Condensers.

WHEN the variable air condenser was first introduced in the early days of radio-telegraphy it was invariably contained in a glass jar with a massive ebonite top. In the ebonite top was a groove into which the jar was fitted with india-rubber packing. The condenser was as air-tight and dust-tight as it was possible to make it. The glass jar had the advantage of enabling one to inspect the spacing between the fixed and moving plates; it also made it possible to convert the air condenser into an oil condenser when it was desired to employ higher voltages, but it made the condenser very bulky and cumbersome. Often, moreover, the glass jar was subsequently lined with tinfoil to make its calibration independent of external influences. For small condensers the glass jars were sometimes replaced by cylindrical brass cases and for larger sizes metal lined wooden boxes replaced the jars.

In those days nobody ever dreamt of using a variable air condenser in its naked condition, in fact, one hesitated to remove it from its case once it had been cleared and put in, for fear that fluffy material floating about the room might get between the plates and thus impair the insulation. Great care was taken to clean the plates and remove any such foreign material either by washing in spirit, or by an air-blast or by sweeping a long pointed flame between the plates, and the condenser was then hurriedly put into its case.

With the advent of broadcasting and the set builder, however, the air condenser entered on a new phase. Tens of thousands of variable air condensers have been built into sets without any protection whatever, although the distance between the fixed and moving plates has been cut down to the absolute miminum. If the set were contained in a dust-proof case, which was rarely opened, the danger of the condensers becoming dirty would be small, but this is very seldom done. Many an experimenter who regards with satisfaction the obvious insulation between the fixed and moving system of his condensers, would be very surprised if he held them up to the light and saw the collection of atmospheric flotsam and jetsam adhering to the plates. The danger is greater with fixed air condensers and we have noted with satisfaction that at least one manufacturer has recently enclosed these in a dust cover. We recently met a case in which reception was being spoilt by a background of noise; after much time had been spent in testing batteries, valves, and other components, the trouble was instantly cured by a puff of the bellows on the air condenser.

In view of the large amount of work which has recently been put into the design of the variable air condenser, it is surprising that more attention has not been paid to the problem of enclosing it in a light metal cover which would serve at the same time as an electrostatic screen and thus prevent any interaction between the condenser and other parts of the apparatus.

A New Development in Resistance Amplification.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

THERE appeared in *The Wireless World* for 23rd September, 1925 (No. 319, Vol. XVII., No. 13, pp. 395-398), a descriptive account by Dr. H. Kröncke of a new development in resistance amplification due to Von Ardenne and Heinert. The distinctive feature of the new method is the employment of anode resistances of much greater magnitude than those which have hitherto been considered suitable. In place of the customary resistances of 50,000 to 100,000 ohms, Von Ardenne and Heinert advocate the use of resistances of the order of megohms.

This drastic departure from former practice is calculated to raise a number of questions in the minds of those who have considered this subject in any detail, and the account

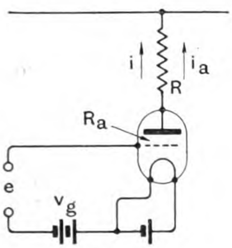

Fig. 1.

given by Dr. Kröncke, clear and explicit though it is, does not really answer these questions.

Hitherto it has been assumed by all those who have written on the subject of the design of resistance-capacity amplifiers (the present writer included) that the anode resistances used should be of such magnitude that the fall of potential in the resistance would still leave sufficient voltage at the anode to ensure that the valve will operate in the straight-line region of its characteristics, even with a negative grid voltage. This condition restricts the magnitude of the anode resistances to about 50,000 ohms for moderate anode battery voltages (150-200). With such comparatively low anode resistances it is easy to show, on the assumption of approximately straight line characteristics for the valve, that the voltage amplification obtainable by the usual circuit arrangement (illustrated in Fig. 1) is

$$\frac{R}{R+R_a}\mu$$

where R_a and μ are respectively the internal resistance and the voltage factor of the valve.

Now it is clear that if anode resistances of 1 to 3 megohms are used, with moderate anode battery voltages of say 50-100 volts, as recommended in the description referred to above, practically the whole of the anode battery voltage will be absorbed in the resistances, leaving a very low voltage, 10 to 20 volts or so, on the anode. Under these conditions the valve will certainly not be operating in the straight-line region of its characteristics, and it might therefore be anticipated that the anode current-grid voltage characteristic with the resistance in circuit (termed by Von Ardenne and Heinert "working characteristic"), would show a pronounced curvature, which curvature would cause partial rectification and distortion in the amplification of low frequency E.M.F.s. Actually, however, the working characteristics obtained under these conditions are remarkably straight over quite useful ranges of grid voltage. A typical example is reproduced from Dr. Kröncke's account in Fig. 2. The question therefore arises, how is it that these working characteristics do not show the curvature that one might anticipate from such low anode voltages? Is it explainable in terms of the known forms of characteristics of ordinary triode valves, or is it possibly a special feature of the type of valve used by these two experimenters?

The object of the present paper is to answer the above questions and to analyse

in general terms the operation of a triode valve with a very high resistance in the anode circuit, illustrating the analysis by reference to typical valves of standard British make. This will make possible a critical discussion of the possibilities of this method of amplification and the determination of the most

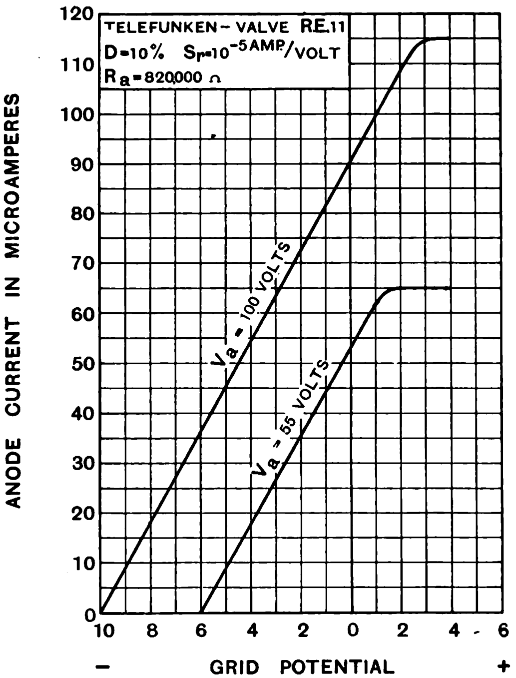

Fig. 2.

suitable magnitudes of the component elements.

It may be stated in advance that the method appears to be very satisfactory, giving a high degree of amplification per stage with a good degree of freedom from distortion. It appears in fact to have all the well-known advantages of resistance capacity amplification combined with a higher degree of amplification per stage than has hitherto been conveniently obtainable, at the same time avoiding the necessity for high anode battery voltages. In qualification of this it should be stated that the claims made for the method in the original paper cannot be fully maintained in practice, and that the estimate of the possibilities of further development are a little over-enthusiastic.

Triode Valve with Resistance in the Anode Circuit.

For the purposes of the analysis it will be assumed that the anode current of a triode valve can be very approximately represented over the whole practicable range of grid and anode voltages (below saturation) by an equation of the form

$$i_a = f(v_a + \mu v_g) = f(V),$$

where

$$V = v_a + \mu v_g.$$

Some experimental confirmation of this will be given later. The idea is one with which readers of this journal are already familiar, for it is implicit in the method of description adopted in the section headed "Some Valves Tested." The "lumped volt" characteristic of a valve, of which a typical example is reproduced in Fig. 3 from p. 968 of No. 27, Vol. II. of this journal, is in fact a curve

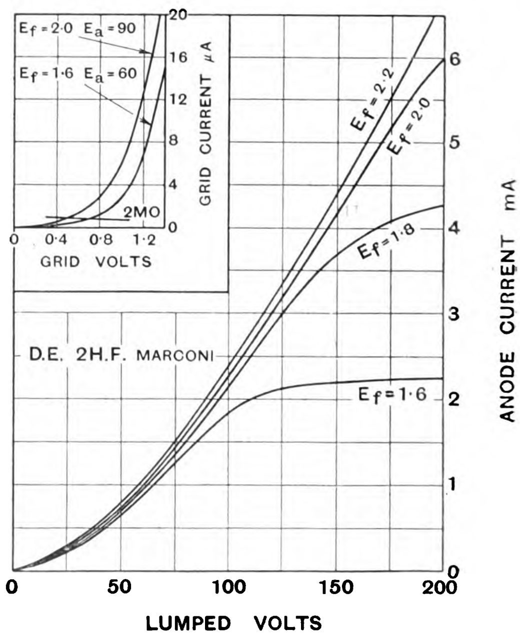

Fig. 3.

showing the variation of the anode current with the lumped voltage V. It has the obvious advantage of describing the valve for a very wide range of grid and anode voltages by means of a single curve, with an accuracy which is quite sufficient for most practical purposes.

The slope of this characteristic is an important quantity in relation to small changes of v_a and v_g. For any given value of V the slope is

$$\frac{\partial i_a}{\partial V} = \frac{\partial f(V)}{\partial V} = f'(V),$$

but since

$$V = v_a + \mu v_g$$

$f'(V)$ is the same as $\partial i_a/\partial v_a$. For a small change δv_a in the anode voltage the corresponding change δi_a in the anode current is given by

$$\delta i_a = \frac{\partial i_a}{\partial v_a}\,\delta v_a$$

$$= \delta v_a \Big/ \frac{\partial v_a}{\partial i_a}$$

so that with respect to these small changes of current and potential the quantity $\delta v_a/\delta i_a$ is in effect a resistance and is usually written R_a. Thus

$$f'(V) = 1/R_a$$

Referring to the typical lumped volt characteristic of Fig. 3, it is seen that in general R_a will not be constant with respect to V. In fact, from $V = 0$ to about $V = 80$ the slope of the characteristic increases steadily, and R_a, which is the reciprocal of the slope, will therefore decrease. From about $V = 80$ up to the saturation point the slope remains very nearly constant. The range of anode and grid voltages, included in the range $V = 80$ upwards to the saturation value of V, correspond to what is known as the straight-line region of the valve characteristics. It is the approximately constant value of R_a corresponding to this region that is intended by the term "internal resistance" in the usual specification of a valve.

In the straight-line region the second differential coefficient of the lumped volt characteristic, *i.e.*,

$$\frac{\partial^2 f(V)}{\partial V^2} = f''(V)$$

is negligibly small. The higher derivatives will also be negligibly small in consequence. For the region corresponding to the lower values of V, the second and higher derivatives of the lumped volt characteristic will have values which are by no means negligibly small.

Consider now the effect of inserting a resistance R in the anode circuit. The anode current will fall to a new value which, since it will be regarded as an initial value with respect to subsequent changes, will be written i_0. There will be a corresponding fall of potential Ri_0 in the anode resistance, and the value of i_0 is therefore given by the implicit relation

$$i_0 = f(v_a - i_0 R + \mu v_a)$$
$$= f(V_0)$$

Suppose now that a small E.M.F. e is added to v_g. There will be a consequent change in the anode current which can be represented as the addition of a small current i, so that the new value for the anode current is $i_0 + i$. (The symbols e and i are used in preference to the more usual but rather more cumbersome symbols δv_g and δi_a, since these changes can be quite legitimately regarded as additional terms superimposed on the existing terms.) The new value of the anode current is related to the anode and grid voltages by the equation

$$i_0 + i = f\{v_a - (i_0 + i)R + \mu(v_g + e)\}$$
$$= f\{V_0 + (\mu e - iR)\}$$

Now the function on the right-hand side can be expanded by Taylor's Theorem into the series

$$i_0 + i = f(V_0) + (\mu e - iR)f'(V_0)$$
$$+\left(\frac{\mu e - iR}{2}\right)^2 f''(V_0) + \left(\frac{\mu e - iR}{6}\right)^3 f'''(V_0) + \text{etc.},$$

and since $\quad i_0 = f(V_0)$

the value of i alone is given by

$$i = (\mu e - iR)f'(V_0)$$
$$+\left(\frac{\mu e - iR}{2}\right)^2 f''(V_0) + \left(\frac{\mu e - iR}{6}\right)^3 f'''(V_0) \text{ etc.}$$

The change of potential across the anode resistance due to this change of grid voltage is $v = iR$. The potential amplification given by the system is therefore v/e. Now for distortionless amplification it is necessary that v/e should not vary with e, *i.e.*, there must be straight-line relationship between v and e. The above equation for i shows, however, that this straight-line relationship between v and e can only be obtained if all the terms beyond the first on the right-hand side are negligibly small. Otherwise the solution for i will clearly contain terms in e^2 and higher powers of e.

Now the terms beyond the first on the right-hand side can be made negligibly small in two ways. In the first place, the initial

value V_0 can be made so large that it falls within the straight-line range of values for V. Under this condition $f''(V_0)$ and the higher derivatives will be negligibly small, and the equation for i will reduce to

$$\begin{aligned} i &= (\mu e - iR)\, f'(V_0) \\ &= (\mu e - iR)/R_a, \end{aligned}$$

R_a being the approximately constant minimum value of this quantity. It is about 25,000 ohms for the valve having the lumped volt characteristic shown in Fig. 3. The solution of the above equation for i gives the well-known form

$$i = \frac{1}{R + R_a}\,\mu e$$

whence

$$Ri = v = \frac{R}{R + R_a}\,\mu e$$

the valve. A higher value than this can only be obtained by increasing R, which will call for a correspondingly higher anode battery voltage. This has always been a disadvantage inherent in the resistance-capacity amplifier designed to operate in the straight-line region of the valve characteristics.

It appears from the straightness of the working characteristics obtained by Von Ardenne and Heinert with anode resistances of the order of megohms that this restriction to the straight-line region of the valve characteristics is not in fact necessary. A further examination of the equation for i will show the reason for this. It will be seen that the coefficients of $f''(V_0)$ and the higher derivatives of the characteristic are $(\mu e - iR)^2$ and higher powers of $(\mu e - iR)$.

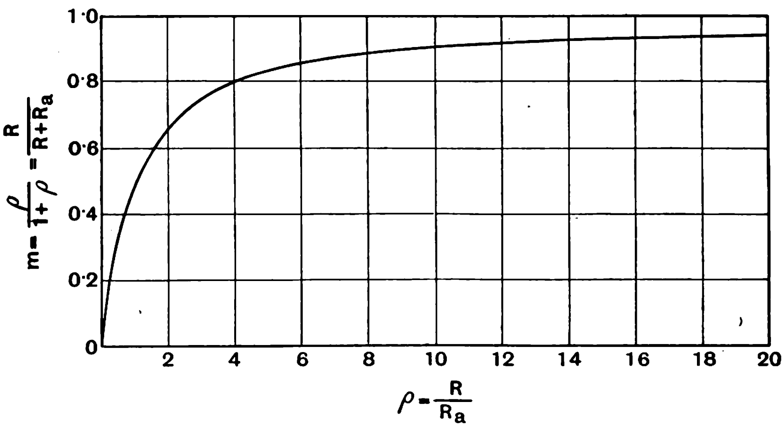

Fig. 4.

The amplification factor is therefore

$$\frac{R}{R + R_a}\,\mu = \frac{\rho}{1 + \rho}\,\mu = m\mu$$

where ρ is written for R/R_a. The variation of m with ρ is shown in the curve of Fig. 4.

Now a reference to the typical lumped volt characteristic will show that, even if the anode battery voltage is rather inconveniently high (150 to 200), R cannot be made much greater than about 40,000 ohms if the straight-line condition is to be satisfied over a useful range of negative grid voltage. This will give about 1.5 for ρ, for which the corresponding value of m is only 0.6. Thus the amplification obtainable free from distortion is only 0.6 of the voltage factor of

If therefore $(\mu e - iR)$ can be made a small quantity, even though μe is not small, then the first term of the series will be large compared with the remaining terms, and there will be in consequence an approximately straight-line relationship between i and e. Now if the terms in $f''(V_0)$, etc., are negligibly small

$$iR = \frac{R}{R + R_a}\,\mu e$$

as already shown, and

$$(\mu e - iR) = \frac{R_a}{R + R_a} \cdot \mu e$$

The expression $(\mu e - iR)$ will therefore be small, provided R is made very large

compared with R_a. This of course is precisely what Von Ardenne and Heinert have done. By making R very large, then is spite of the fact that V_0 is now very small and R_a correspondingly larger than its straight-line magnitude, R will still be large enough compared with R_a to satisfy the above condition, and a very approximately straight line working characteristic will result.

Notice also that the amplification factor under these conditions will be, as before,

$$\frac{R}{R_a + R}\,\mu$$

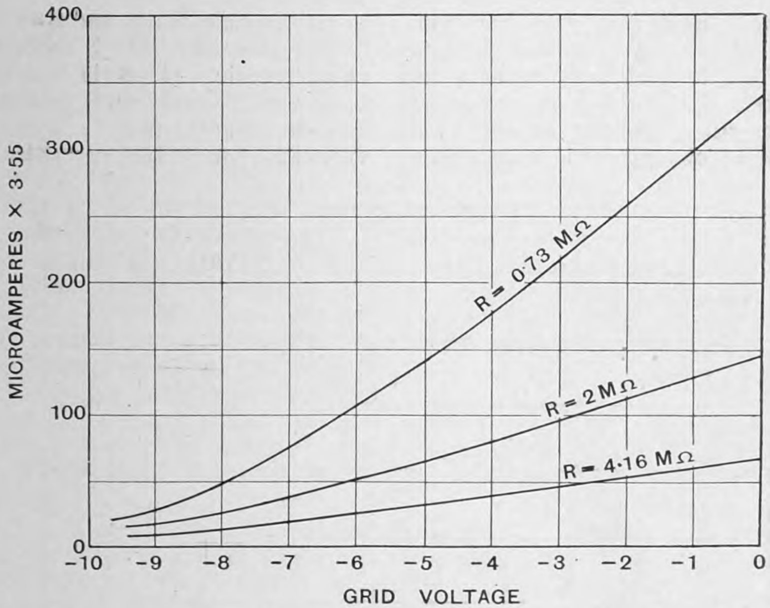

Fig. 5. *Valve DE2HF.; Anode battery voltage,* 100; *Normal filament voltage,* 1.8; *Actual filament voltage,* 1.18; *Voltage factor (normal filament)* 9.5; *Amplification factors (mean values),* R=.73 MΩ 8.0; R=2 MΩ, 8.44; R=4.16 MΩ, 8.1.

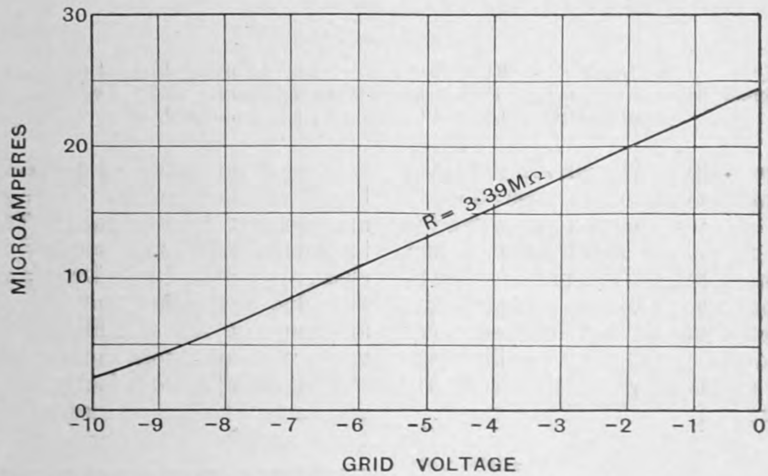

Fig. 6. *Valve DER; Anode battery voltage,* 100; *Normal filament voltage,* 1.8; *Actual filament voltage,* 1.2; *Voltage factor (normal filament),* 7.8; *Amplification factor,* 7.4.

and since R is now very large compared with R_a this will be nearly equal to μ so that nearly the full voltage factor is operative.

It is found that the condition can be fulfilled satisfactorily in practice by making R from 1 to 3 or 4 megohms according to the type of valve used. It must be remembered that the approximate rectilinearity will only obtain as long as R is large compared with R_a. Now R_a will increase continuously as the grid is made more and more negative so that the foot of the working characteristic will necessarily be curved as it is in the normal characteristic, approaching the axis tangentially. The curves published in Dr. Kröncke's account are misleading in this respect. They are shown as cutting the bottom axis at quite a sharp angle, a fact which suggests a certain amount of unjustifiable extrapolation with a straight-edge. However, the actual curves, plotted point by point, show a satisfactory rectilinearity over a very useful range of negative grid voltage (about —2 to —8 in some cases).

The curves of Figs. 5, 6 and 7 show the actual characteristics obtained with very high anode resistances for valves of various well-known types. (The actual selection does not in any way imply any special merit or even special suitability in the valves specified. They are simply taken as typical of valves of their respective kinds, and any others having similar characteristics would do equally well.)

It will be seen that the lines are sensibly straight over quite considerable ranges of negative grid voltage, and that in general the higher the value of R the straighter the characteristic. (There is, however, an upper limit for R which will be discussed later.) In estimating the useful range of grid voltage variation it must be remembered that about —2 must be taken as a permissible upper limit, at least as far as any multi-stage arrangement is concerned. This is a very important point, and one which is not sufficiently emphasised in Dr. Kröncke's paper. It is due to the fact that in any multi-stage arrangement the grid-filament path is virtually a shunt across the anode resistance of the preceding valve (a fact which was strongly emphasised by the present writer some three years ago.)*

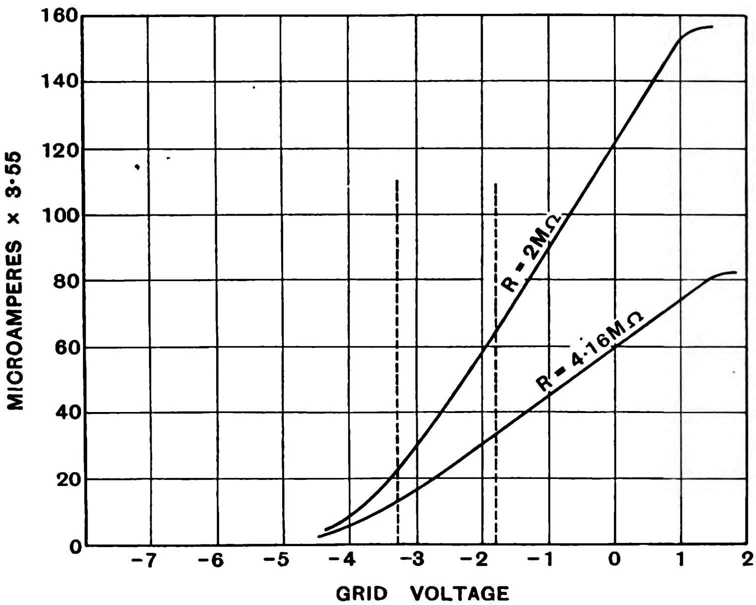

Fig. 7. *Valve DE5B; Anode battery voltage,* 100; *Normal filament voltage,* 5; *Actual filament voltage,* 2.4; *Voltage factor (normal filament),* 18.8; *Amplification factor (mean values),* R=2.0 MΩ, 16.7; R=4.16 MΩ, 17.2.

* "Grid-filament Conductivity: Its Effect on Amplification." *Electrician*, Nov., 1923.

Grid-filament conductivity must therefore be avoided, especially when, as in the present case, the anode resistance is of the order of megohms. The circuit illustrated in Fig. 7 in Dr. Kröncke's account is wrong in this respect.

The lower limit of the permissible voltage range is fixed by the curvature of the foot of the working characteristic. It will be observed that there is not a very wide range left between these limits in the case of the high voltage factor valve. This consideration sets a limit to the amplification obtainable by specially designed triode valves unless very high anode battery voltages are available, or unless the signal amplitude is small, a fact which should be borne in mind in connection with the somewhat enthusiastic estimates of future possibilities contained in the paper referred to above.

An additional useful feature of the method can be noted at this point. Valves operating under these conditions, with anode currents of the order of micro-amperes, require much less than normal filament emission, and it is found in practice that a reduction of the filament current to something like 60 per cent. of its normal value is not only harmless, but actually beneficial. Von Ardenne and Heinert appear to attribute the straightness of the working characteristics in part to this lowering of the filament current, and the consequent reduction of the space charge in the valve. This does not seem at all clear to the present writer. The comparative straightness of the working characteristics is due to the reason given above, of which experimental confirmation will be given. It seems more probable that any effect of the reduction in the filament current will be a secondary one due to the fact that the filament will now approximate more closely to an equipotential surface. There is, in fact, a small increase in the voltage factor with the lower filament current which may be attributable to this cause. Apart from these theoretical considerations, however, the permissible reduction in the filament current is undoubtedly a very useful feature of the method, making for longer life of the valves and for convenience in the low tension supply.

Some degree of confirmation of the above analysis, at least in respect of the fundamental assumptions on which it is based, is obtainable in the following manner. If

$$i_0 = f(v_a - Ri_0 + \mu v_g)$$

as assumed, then it is easy to show that

$$\partial i_0 / \partial v_a = 1 / (R + R_a)$$

and $$\partial i_0 / \partial v_g = \mu / (R + R_a)$$

where R_a has the meaning already attached to it.

The slope $\partial i_0/\partial v_g$ can be measured directly from the working characteristic. Values of $\partial i_0/\partial v_a$ for various values of v_g were obtained by making small variations in v_a when the working characteristics were being determined. (There is no need to specify the experimental details. The measurements involved are of a very simple character, and do not require any special precautions beyond those implied in any work with valves and with high resistances.) From these two terms, both μ and R_a can be calculated, though since it is a feature of the method that the slope of the working characteristic should not vary much with R_a, it is not a very accurate way of determining the latter. The important factor, however, is μ, for the method assumes that this will not vary appreciably even in the rather extreme conditions of operation of the valve. Some typical results are exhibited in the following table. It will be seen that the calculated values of μ show a satisfactory constancy as the theory requires; also that the values are in every case somewhat higher than those corresponding to normal filament heating.

Valve.	R (megohms)	V_g	$\frac{\mu \times 10}{R+R_a}$	$\frac{10^6}{R+R_a}$	R_a (megohms)	μ	μ (Norma Fil. Curr.).
DE2HF	·73	+1	12·4	1·2	·103	10·33	9·5
,,	,,	—3	10·95	1·09	·118	10·05	,,
,,	,,	—6	9·42	·928	·347	10·15	,,
,,	4·16	0	1·99	·198	1·05	10·04	,,
,,	,,	—3	1·91	·191	1·07	10·02	,
,,	,,	—6	1·83	·185	1·26	10·05	,
SP18	2	0	6·82	·478	·09	14·25	13·06
,,		—3	6·37	·413	·31	14·40	,,
,,	·73	0	17·3	1·26	·06	13·7	,,
,,	,,	—3	15·5	1·12	·16	13·8	,,
DE5B	2	0	8·8	·41	·26	19·9	18·8
,,	2	—3	7·9	·37	·73	21·5	18·8

The Effect of a Small Degree of Curvature.

The rectilinearity obtained by making R large compared with R_a is not perfect, as inspection of the experimental curves will show. It is therefore desirable to consider the effect of the residual slight curvature. For this purpose it will be sufficiently accurate to assume that the relationship between i and e can be expressed in the form

$$i = \frac{\partial i_0}{\partial v_g} e + \frac{1}{2} \frac{\partial^2 i_0}{\partial v_g^2} e^2$$

since the curvature of the working characteristic is sufficiently small to be representable as a square law over the range e of grid voltage variation. Suppose now that e is a simple sine function of time, *i.e.*, that the variation of grid potential is a pure low frequency tone

$$e = \hat{e} \sin nt.$$

A full analysis should now take account of the effect of the inter-electrode and other stray capacities in the system, the effect of which, as shown later, will not be negligible in general. This would, however, rather obscure the present issue, so it will be assumed that the frequency is low enough to minimise any such secondary effects. The equation for i now becomes

$$i = \frac{\partial i_0}{\partial v_g} \hat{e} \sin nt + \frac{1}{2} \frac{\partial^2 i_0}{\partial v_g^2} \hat{e}^2 \sin^2 nt$$

$$= \frac{\partial i_0}{\partial v_g} \hat{e} \sin nt + \frac{\partial^2 i_0}{\partial v_g^2} \frac{\hat{e}^2}{4} - \frac{\partial^2 i_0}{\partial v_g^2} \frac{\hat{e}^2}{4} \cos 2nt$$

From this it appears that i will consist of three terms—a continuous component i_c, a fundamental frequency component i_n, and a double frequency component i_{2n}, *i.e.*,

$$i = i_c + i_n + i_{2n} = \frac{\partial i_0}{\partial v_g} \hat{e} \sin nt + \frac{\partial^2 i_0}{\partial v_g^2} \frac{\hat{e}^2}{4} - \frac{\partial^2 i_0}{\partial v_g^2} \frac{\hat{e}^2}{4} \cos 2nt.$$

By a well-known principle the above single equation can now be broken up into three separate equations, containing respectively continuous, single frequency, and double frequency terms. This will lead to the following results for the amplitudes of the various components of the current :

$$\hat{i}_c = \hat{i}_{2n} = \frac{\partial^2 i_0}{\partial v_g^2} \frac{\hat{e}^2}{4}$$

$$\hat{i}_n = \frac{\partial i_0}{\partial v_g} \hat{e}$$

It should be observed that the expression for i_n is consistent with that deduced from first principles above, for, as already shown,

$$\frac{\partial i_0}{\partial v_g} = \frac{\mu}{R + R_a}$$

so that

$$\hat{v}_n = R\hat{i}_n = R \frac{\partial i_0}{\partial v_g} \hat{e} = \frac{R}{R + R_a} \mu\hat{e}$$

The important thing to notice is that the curvature of the working characteristic introduces a double frequency term not present in the original E.M.F., so that the potential difference across the anode resistance is no longer that corresponding to a single pure tone. The fair estimate of this frequency distortion will be the ratio of this extraneous double frequency potential difference to the single frequency potential difference. From the above equations,

$$\hat{v}_{2n}/\hat{v}_n = \frac{1}{4} \left(\frac{\partial^2 i_0}{\partial v_g^2} \Big/ \frac{\partial i_0}{\partial v_g} \right) \hat{e}$$

For any given case the ratio of the differential coefficients can be determined by actual measurement of the working characteristic. For instance, for the DE2HF valve with 2 megohms in the anode circuit and $v_g = -6$ (see Fig. 5).

$$\partial^2 i_0/\partial v_g^2 = .172 \times 10^{-6}$$

$$\partial i_0/\partial v_g = 39.7 \times 10^{-6}$$

so that

$$\hat{v}_{2n}/\hat{v}_n = .011\hat{e}$$

Thus the ratio of the extraneous to the true frequency is about 1.1 per cent. per volt (amplitude). This will almost certainly be quite inappreciable by ear, so that the residual curvature in this fairly typical case should not cause any noticeable frequency distortion. It will in any case be negligible compared with frequency distortion associated with other elements of the complete receiving circuit. In general, it would appear that the effect of small degrees of curvature in producing double frequency tones is less than one would imagine without a detailed analysis.

Multi-stage Amplifiers.

The discussion so far has been concerned with a single valve only. It remains to be considered briefly to what extent the useful features of this method can be maintained when more than one stage of amplification is

required. It will be assumed that the potential change across the anode resistance of the valve is transferred to the grid of the next valve by means of the usual capacity and grid-leak arrangement illustrated in Fig. 8.

The first thing to notice is that the effect of the inter-electrode and other stray capacities (indicated by dotted lines in Fig. 8) will certainly not be negligible, even though only audible frequencies are contemplated. For

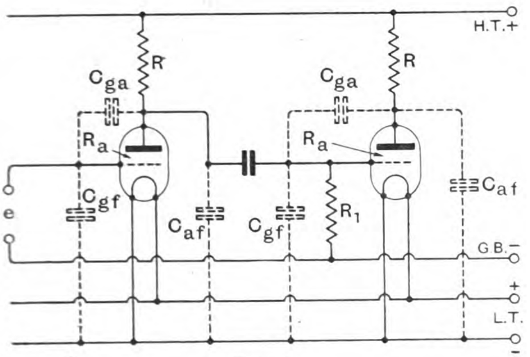

Fig. 8.

instance, assuming only 5 micro-microfarads for C_{gf}, which is a shunt on the grid-leak, the reactance of this capacity at a frequency of about 8,000 will only be about 4 megohms. Thus, over the whole audible frequency range the effective impedance of the grid-leak will vary from its direct current value to something less than 4 megohms. To limit the effect of this variation the grid leak should not exceed 5 or 6 megohms. The permissible value for the anode resistance is limited by similar considerations. In general 1 to 2 megohms is the most suitable value for this, though a somewhat higher value is more suitable for a high voltage factor valve, such as the DE5B, the internal resistance of which will itself be considerably higher under the conditions of operation than that of an ordinary general-purpose valve.

It seems to be generally thought, and the writer confesses that he himself was under the same impression until he examined the matter more closely, that the grid-leak must be made large compared with anode resistance. Actually this is not the case, as will be demonstrated later. What is required is that the grid resistance shall be large compared with the internal slope resistance of the preceding valve, which is a very different matter.

For a complete analysis of the coupling conditions it would be necessary to take into account all the inter-electrode and other stray capacities. This makes a very complicated problem, and will not be attempted here. As far as the coupling condenser is concerned, the lowest audible frequency required to be transmitted will be the most exacting case, and its suitable value will be deduced for this condition, which will permit of the effect of stray capacities being neglected. On this assumption a single valve with its associated coupling condenser and grid-leak can be represented very approximately by the network shown in Fig. 9. The potential transmitted to the grid of the next valve at a frequency $n/2\pi$ will be V, for the determination of which we have the vector equations

$$I(R_a + R) - RI_1 = \mu E$$

$$I_1(R + R_1 + 1/jnC) - RI = 0$$

The solution of these two simultaneous equations presents no difficulty, and will lead to the result for V, *i.e.*, for R_1I_1,

$$R_1I_1 = V = \left(\frac{R_1}{R_1 + Z}\right)\left(\frac{R}{R + R_a}\right)\mu E$$

where
$$Z = \frac{RR_a}{R + R_a} + \frac{1}{jnC}$$

It should be noted that the resistance term of Z is the resistance of R and R_a in parallel.

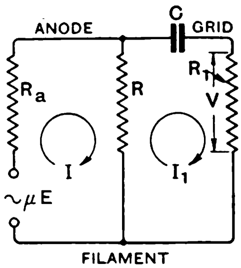

Fig. 9.

The form of the expression for V is interesting. It shows that the original magnification factor $R/(R_a + R)$ has to be multiplied by another factor of the same form as a result of the coupling, the only difference being that this factor is one involving both magnitude and phase. It shows that even if the value of C be so chosen that Z does not

differ much in magnitude from its resistance component, there will still be a reduction of the effective magnification factor, given by $R_1/(R_1+R_0)$ where R_0 is the resistance of R and R_a in parallel. The reduction will be small provided R_1 is large compared with R_0, *i.e.*, provided R_1 is large compared with R_a, since R is large compared with R_a.

The determination of the suitable value for C is now quite simple. It depends only on the permissible variation of the coupling factor with frequency. The maximum value of the latter, at high frequencies, when the reactance of the condenser will be negligibly small, is $R_1/(R_1+R_0)$. Suppose it is required that the coupling factor shall not vary by more than 5 per cent. down to a frequency of about 80 per second, for which n can be taken as 500. It is only a question of solving graphically or otherwise

$$| R_1 + R_0 + 1/jnC | = 1.05(R_1 + R_0),$$

the vertical strokes indicating that the magnitude of the complex expression is

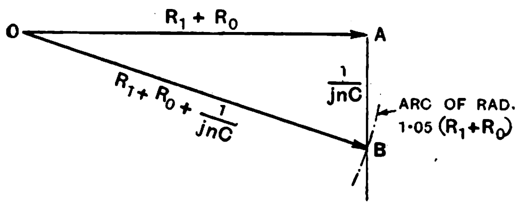

Fig. 10.

$$OA = R_1 + R_0 = R_1 + \frac{RR_a}{R+R_a} = 5.33M\Omega$$

$$OB = 1.05\ (R_1+R_0) = 5.6M\Omega$$

$$\therefore \quad AB = 1/nC = 1.75M\Omega$$

considered. The graphical calculation is illustrated in Fig. 10 for the following values:

$R = 2$ megohms
$R_1 = 5$ megohms
$R_a = .4$ megohm.

It is found that $1/nC$ must not exceed 1.75 megohms, which gives a minimum value of about 1,200 micro-microfarads for C. In general, anything from one to two thousand micro-microfarads will probably be a suitable value. The coupling capacity should not be made larger than is necessary, as this will increase unnecessarily the time constants of the various parts of the amplifier. Von Ardenne and Heinert give 500 micro-microfarads as a suitable value, and state that the criterion is that this capacity should be large compared with the grid-filament capacity. This, however, is not the true criterion and would lead to an under-estimation of the right value for C.

It might be mentioned at this point that the insulation resistance of the coupling condenser is a very important matter, particularly with a high value for the grid resistance. It must be at least 500 megohms.

Limitations on the Maximum Amplification obtainable.

In the account given by Dr. Kröncke it is stated that it is hoped to obtain an amplification factor of 70 with a single stage by this method, using valves having a very small "Durchgriff," *i.e.*, a very large voltage factor. There is, however, a limiting factor here. A very large voltage factor cannot be obtained without a corresponding increase in the internal slope resistance of the valve, which requires a correspondingly larger value of the anode resistance if the full value of the voltage factor is to be obtained. The upper limit of the value of this anode resistance is, however, already fixed by the inter-electrode and other stray capacities necessarily involved in the system. It is doubtful if a higher value than four megohms can be used without introducing the possibility of considerable variation in amplification with frequency, particularly at the higher frequencies, when the shunting effect of the stray capacities will be more pronounced. Further, the steepness of the working characteristic implied by the large voltage factor greatly reduces the permissible range of grid voltage variation unless a high voltage anode battery is used (see Fig. 5), so that even if these high magnifications can be obtained they would in general only be available for the first stage with comparatively small voltage amplitudes. Subject to this limitation, however, amplifications of seventeen to twenty-five per stage can be obtained by means of high voltage factor triodes and possibly even greater amplification per stage if four-electrode valves are used.

Conclusions.

Low frequency amplification by means of resistance capacity couplings with anode resistances of the order of megohms can be stated to have the following characteristics :—

1. An amplification per stage amounting to from 80 to 95 per cent. of the voltage

factor of the valve used. For small amplitudes (up to about one volt) an amplification of at least twenty per stage can be obtained by means of high voltage factor triodes. These results can be obtained with comparatively low anode battery voltages, say, seventy to one hundred volts.

2. Valves used in this way require in most cases considerably less than normal filament current. This makes for longer life in the valves and for convenience of low tension supply.

3. Low frequency amplification by this method will be practically free from amplitude or frequency distortion, if the component magnitudes are suitably chosen.

The following are suggested :—

Anode resistances—1 to 2 megohms, for normal H.F. valves ; 2 to 3 megohms for high voltage factor valves.

Grid-leaks—3 to 5 megohms.

Coupling condensers—1,000 to 2,000$\mu\mu$F.

The following precautions must be observed in the design of any amplifying system using this method :—

1. Sufficient negative grid bias must be applied to each valve following a resistance stage to ensure that the grid voltage does not at any time rise above about two volts negative.

2. The insulation resistance of all components used must be as high as possible.

3. The wiring and valve sockets must be such as to reduce to a minimum the stray capacities of the system. The resistances used must also be of low self-capacity. The "Loewe" resistances mentioned in the account by Dr. Kröncke are suitable in this respect, but the ordinary grid leaks of standard make appear to be satisfactory also.

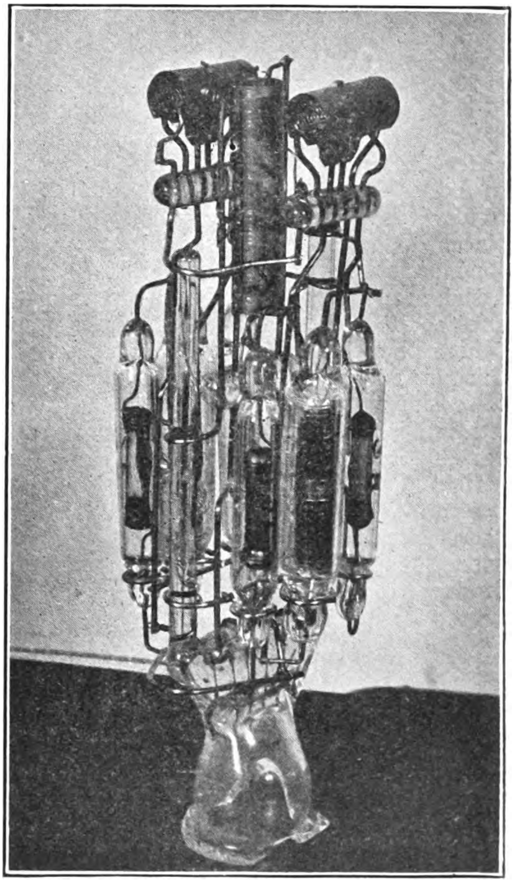

Fig. 11. *Photograph showing the assembly of the elements in the Loewe multiple valve.*

The Resultant Capacity of Aerial Systems Employing Series Tuning Condensers.

By W. H. F. Griffiths.

IN a recent article in this journal* the author developed a number of formulæ for the design of variable air condensers to have certain definite laws connecting resultant capacity change and angular displacement when in series with fixed value condensers. Among the cases in which the design of such condensers becomes of importance is that of the *series* aerial tuning condenser of a wireless receiving system. In this particular case, however, it is impossible to design variable condensers which will *always*, when connected as continuously variable tuning adjusters in series with given aerials, have definitely uniform and predetermined scale laws irrespective of other aerial circuit conditions. In other words, even though the effective aerial capacity is known, the case of the aerial series condenser cannot *always* be treated as simply

$$C_R = C_f C / C_f + C \qquad \ldots \quad (1)$$

where C_f = fixed series capacity (aerial capacity),
C = variable tuning capacity,
and C_R = resultant capacity of C and C_f in series.

The operation of "tuning" a circuit to resonance with the frequency of an impressed electromotive force is merely one of adjusting the total inductance or total capacity of that circuit so that the algebraic sum of all the reactances is zero at that frequency. If two capacities are in series in the circuit being tuned, their reactances are simply added arithmetically in order to obtain the total *capacitive* or *negative* reactance. The reactance of the series aerial tuning condenser cannot, however, be added to the negative reactance of the aerial because the latter has its capacity and inductance distributed more or less evenly throughout its length; it has no "lumped" capacity the reactance of which can be separately expressed quantitatively without reference to its distributed inductance. Its reactance cannot, in other words, be stated as

$$j\omega L_f + \frac{-j}{\omega C_f} \qquad \ldots \quad \ldots . \quad (2)$$

The reactance $1/\omega C$ of the tuning condenser cannot therefore be directly added arithmetically to $1/\omega C_f$, in order to obtain the total capacitive reactance of the aerial *circuit* for the evaluation of ω for "reactance balance" or resonance.

Particularly is it incorrect to add the capacitive reactances of aerial and series condenser when the aerial system is tuned only by that condenser, no loading inductance being employed (see Fig. 1a); in this case the wavelength of the aerial cannot be reduced to less than half its natural (unloaded) wavelength however high the reactance of the condenser be made.

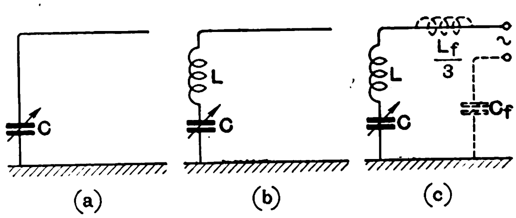

Fig. 1.

In most practical cases of receiving aerial tuning (Fig. 1b) in which there exists a loading inductance of over twice the value of the aerial inductance, it *is* permissible, however, to treat the aerial capacity as merely a fixed value condenser in series with the variable tuning condenser as shown in Fig. 1c. The resultant capacity is given by (1) and the formulæ given in the previous article may therefore be used in the design of the variable condenser.

In practice the condition

$$L > 2L_f$$

is fulfilled for small aerials for all but the shortest wavelengths. A loading coil, L, of twice the value of the aerial inductance, is

* December, 1926.

required to raise the wavelength to about 2.4 times that of an unloaded aerial and if a series tuning condenser is then introduced the wavelength may again be reduced to the original unloaded value. The unloaded wavelengths of small receiving aerials may be from 100 to 200 metres, and for all wavelengths above this order therefore the condition $L > 2L_f$ may be fulfilled by suitably proportioning L and C. For wavelengths above $2.4 \times (100$ to $200)$ the condition *must* be fulfilled irrespective of the proportioning of L and C.

The reactance of an unloaded aerial having uniformly distributed inductance and capacity can be shown to be—

$$X_f = -\sqrt{\frac{L_f}{C_f}} \cdot \operatorname{Cot} \omega\sqrt{C_f L_f} \quad \ldots \quad (3)$$

an expression which, if the cotangent is expanded into a series omitting all terms after the second, gives the usual approximation of the equivalent circuit of Fig. 1c:—

$$X_f = -\sqrt{\frac{L_f}{C_f}}\left(\frac{1}{\omega\sqrt{C_f L_f}} - \frac{\omega\sqrt{C_f L_f}}{3} \cdots\right)$$

$$= -\frac{1}{\omega C_f} + \frac{\omega L_f}{3}$$

In practice, when tuning with a variable condenser in series with the receiving aerial, the reactance of the latter, X_f, is fixed for a given wavelength of signal to be received, the reactance, X_L, of the inserted loading coil is also fixed by selection and the reactance X_C of the variable condenser is adjusted until the algebraic sum of X_f, X_L and X_C is reduced to zero.

As an example of this "reactance balancing," a case equivalent to those given in the design examples of the previous article will be taken, using values of $500\mu\mu$F aerial capacity (150 feet long and 206.5 metres natural, unloaded, wavelength) and a variable tuning condenser of $500\mu\mu$F maximum capacity and $36\mu\mu$F minimum capacity. The inductance of the aerial is 59μH, and when a loading coil of 680μH is inserted in the downlead in addition to the variable condenser, the wavelength curve $\lambda = 50\sqrt{C_R}$ given in Fig. 8 of the previous article is obtained.

In Fig. 2 are plotted curves giving the reactance values of aerial, loading inductance and tuning condenser for various frequencies. The reactance curve for the unloaded aerial appears as the cotangent curve plotted from the expression for X_f (3) above, for values of the angle $\omega\sqrt{C_f L_f}$ from 0 to π, the natural unloaded frequency being indicated at the zero reactance portion of the curve as 1.45×10^6 cycles=206.5 metres at the point where angle $\omega\sqrt{C_f L_f} = \pi/2$.

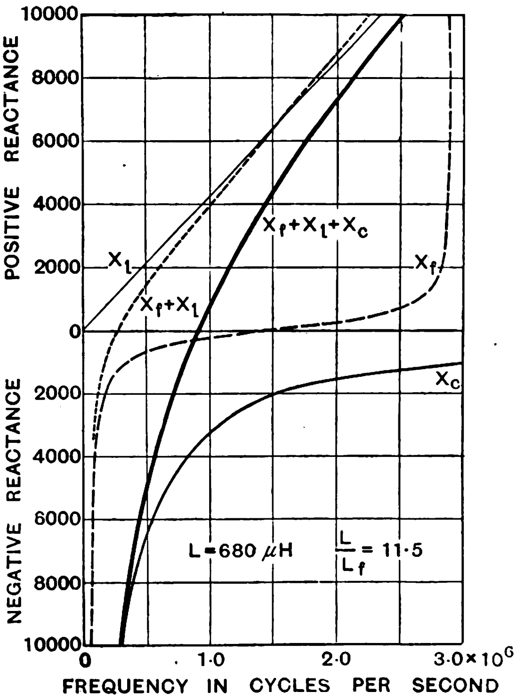

Fig. 2.

Frequencies less than the natural frequency give the angle $\omega\sqrt{C_f L_f}$ values less than a right angle and its cotangent is therefore positive, making the reactance negative, whereas frequencies greater than the natural frequency (but less than twice this value) make the angle greater than a right angle, so that, its cotangent being negative, the reactance becomes positive.

The reactance X_L of the loading inductance is a straight line, being directly proportional to frequency and the reactance X_C of the series tuning condenser, adjusted to $50\mu\mu$F capacity—one-tenth of its maximum value—is a hyperbola since it is inversely proportional to frequency.

The resultant reactance for the complete aerial system $X_f + X_L + X_C$ is the algebraic sum of the three curves at any frequency and

In the same figure is given the reactance curve $X_f + X_L$ of the aerial and loading inductance in series when the series capacity

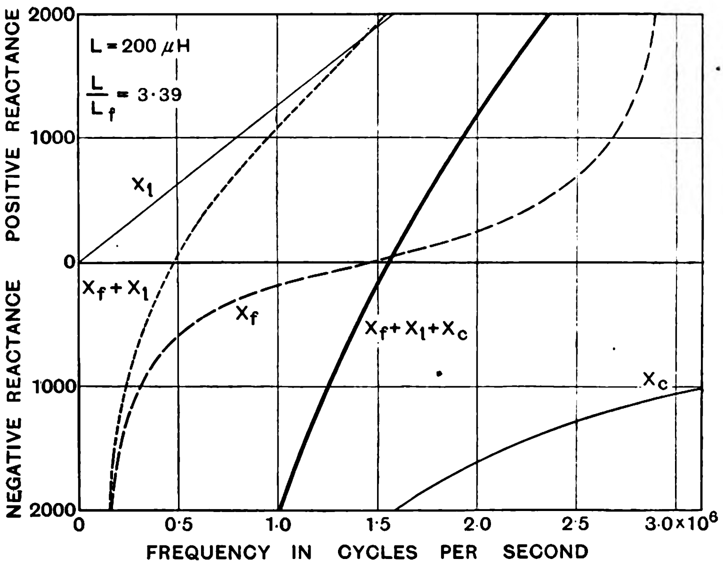

Fig. 3.

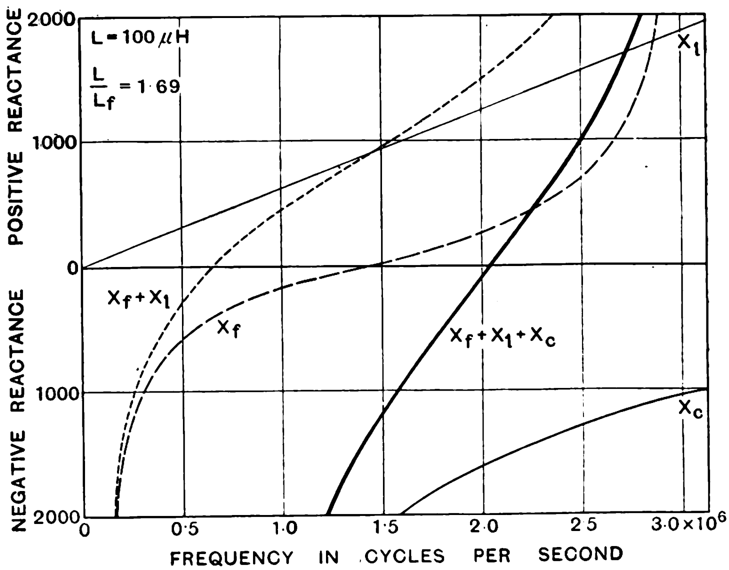

Fig. 4.

the frequency of the point at which the curve representing this resultant reactance crosses the zero reactance ordinate corresponds to the resultant resonant wavelength of the system.

is increased to infinity (short-circuited) and for this condition the frequency at which the positive reactance of the loading inductance is arithmetically equal to the negative reactance of the aerial is shown by the

intersection between the resultant reactance curve and the zero reactance ordinate.

In this way, from these two resultant reactance curves $X_f + X_L + X_C$ and $X_f + X_L$, two values of resonant frequency are obtained —one with a series condenser of one-tenth of the aerial capacity, and the other without that condenser. From the ratio of these two frequencies it is possible therefore to find the error introduced by assuming that

$$C_R = \frac{C_f C}{C_f + C}$$

For the case for which the curves of Fig. 2 are plotted $C = 0.1\ C_f$

and $$C_R = \frac{500 \times 50}{550} = 45.5\mu\mu\text{F}$$

∴ the ratio of resultant capacities computed in this way with series condenser and without

$$= \frac{500}{45.5} = 11.0$$

The ratio therefore of resonant frequencies or wavelengths calculated on this assumption would be $\sqrt{11.0} = 3.32$ whatever the value of L.

From the two resultant reactance curves of Fig. 2 the two resonant frequencies are seen to be 9×10^5 and 2.71×10^5, giving a ratio of 3.32. In this case therefore the assumption is justified, but if this process is repeated for values of loading inductance 200μH (Fig. 3), 100μH (Fig. 4), 68μH (Fig. 5), 34μH (Fig. 6) and zero (Fig. 7), keeping constant, at $50\mu\mu$F, the value to which the series tuning condenser is adjusted, the frequency ratios given in the following table are obtained.

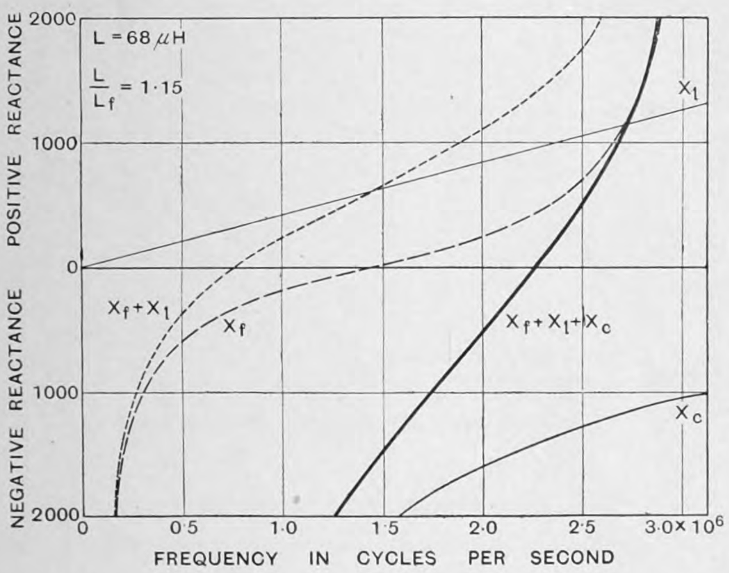

Fig. 5.

L μH	Ratio $\frac{L}{Lf}$	Resonant frequencies With $50\mu\mu$F Series Condenser f_1	Resonant frequencies Without Condenser f_2	$\frac{f_1}{f_2} = \frac{\lambda_2}{\lambda_1}$	Resonant frequencies obtained from reactance curves of :
680	11.5	9.0×10^5	2.71×10^5	3.32	Fig. 2
200	3.39	1.56×10^6	4.82×10^5	3.24	Fig. 3
100	1.69	2.05×10^6	6.50×10^5	3.15	Fig. 4
68	1.15	2.26×10^6	7.50×10^5	3.01	Fig. 5
34	0.58	2.51×10^6	9.50×10^5	2.60	Fig. 6
0	0	2.62×10^6	1.45×10^6	1.87	Fig. 7

It is seen from this table that as the ratio L/L_f of loading inductance to aerial inductance is reduced the error introduced by the assumption of "lumped" negative aerial reactance becomes apparent, until, when

L/L_f is less than 2 the error ceases to be negligible.

In Fig. 8 these results have been plotted inductance to aerial inductance. This figure also shows the percentage error of wavelength ratio obtained for various values of

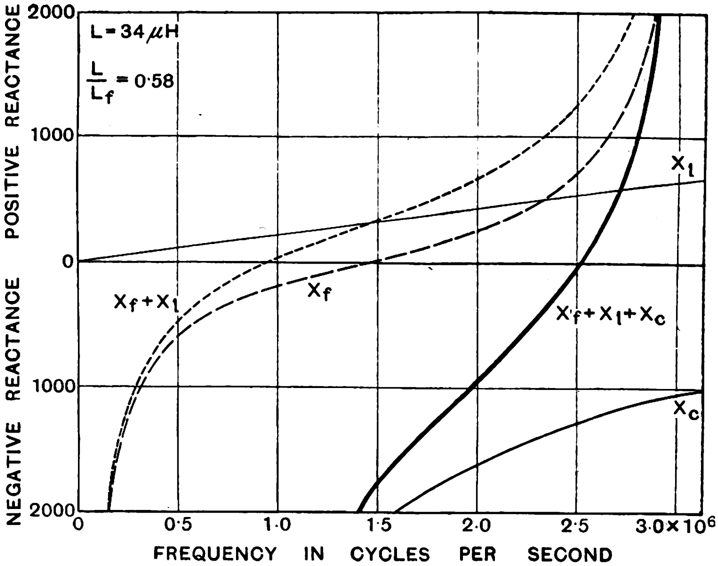

Fig. 6.

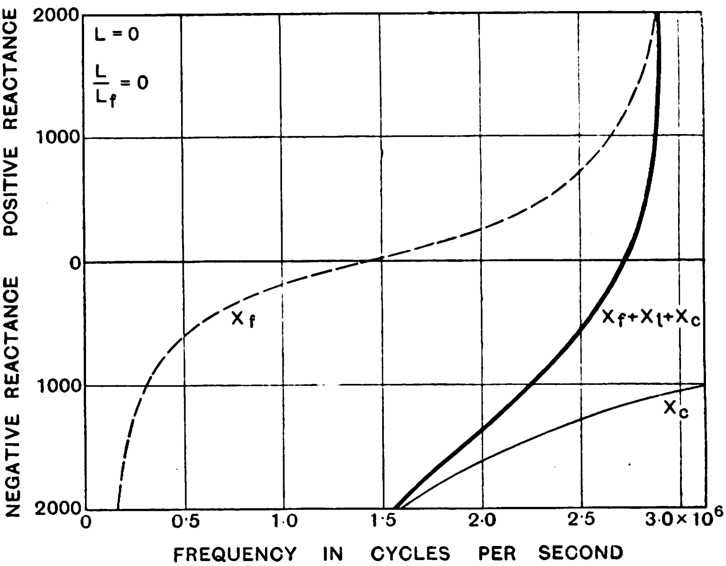

Fig. 7.

as wavelength (or frequency) ratios (when a series aerial tuning condenser of one-tenth of the aerial capacity is switched in or short-circuited) against ratios of added loading L/L_f when the assumption

$$C_R = \frac{C_f C}{C_f + C} \text{ is made.}$$

Since these curves are plotted for *ratios* of L/L_f they are correct for aerials of any natural wavelength or capacity, but it should formulæ for the determination of the wavelength of an inductance loaded aerial.

A careful study of the reactance curves of

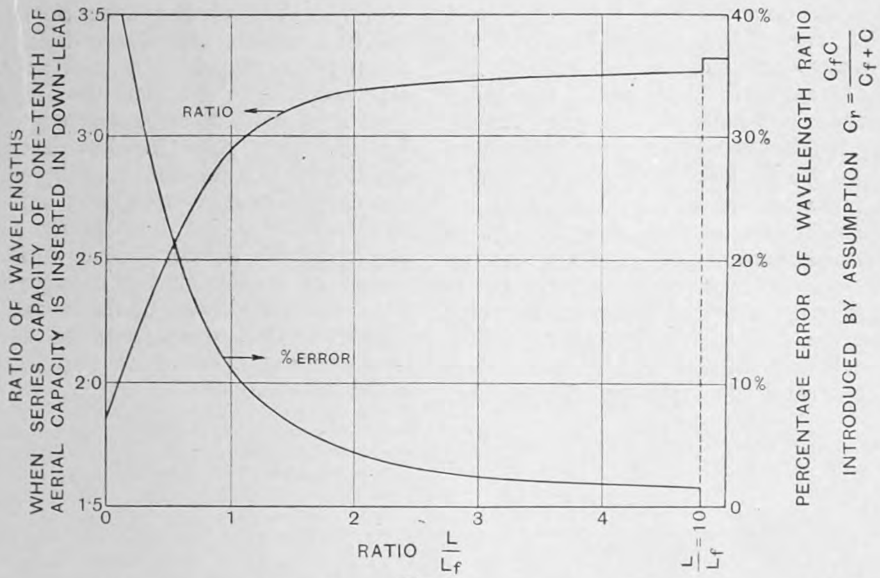

Fig. 8.

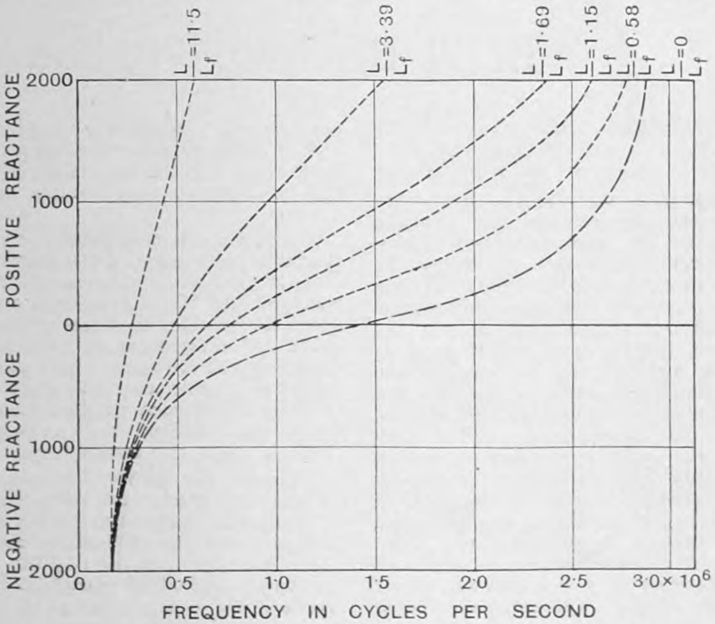

Fig. 9.

be noted that L_f is the *total* value of aerial distributed inductance and *not* one-third of the latter as is used in the approximate Figs. 3, 4, 5, 6 and 7, all plotted to the same scales of frequency and reactance, will provide a good mental picture of the effect of

varying the value of the loading inductance upon the tuning of an aerial by a series condenser.

It will be observed from Fig. 7 that, when there is no loading inductance in series with the aerial, even if the reactance X_c of the series condenser is increased to infinity, the wavelength cannot, by its use, be reduced to less than one-half the unloaded value, since the two frequencies at which reactance balance occurs in this case are for angles $(\omega\sqrt{C_f L_f})$ having values of π and $\pi/2$.

The straightening of the curve $X_f + X_L$ of the combined reactance of aerial and loading inductance as the ratio L/L_f is increased is shown in Fig. 9, the cotangent curve character becoming less evident with increasing ratios.

In conclusion, it should be stated that there are several other sources of error due to the self-capacity of loading inductance and stray capacities from various high potential points, etc., but these, although affecting the resultant wavelength *value*, are generally insufficient to affect appreciably the *law* of a variable condenser designed on the assumption justified by this article, more especially as, in practice, the lower limit of resultant capacity is generally greater than $50\mu\mu$F. It is seen therefore that if a series aerial tuning condenser is designed, treating the aerial capacity merely as a fixed value condenser in series, its "design law" will, in general, be approximately correct for all values of loading inductance greater than twice the inductance of the aerial and very closely correct when used in conjunction with loading coils of over ten times the aerial inductance.

Book Review.

THE ELEMENTS OF RADIO-COMMUNICATION. By O. F. Brown. Pp. 213, with 146 illustra ions and diagrams. Oxford University Press 1927. 10s. 6d.

It is a remarkable thing that the intensive study of wireless phenomena during the last few years has not been accompanied by a corresponding intensive production of wireless handbooks embodying the phenomenal progress of the period. Much has been written in a simple, popular, and often very attractive way, about wireless receiving circuits and the way they function, but of more ambitious text-books there have appeared hardly any. There seem to be two possible reasons for this. In the first place we are not a nation of text-book writers. To realise this we have only to compare the enormous output of text-books in German on such a subject as Relativity compared with the meagre output of works of similar character in this country. Secondly, a not unimportant reason, the writing of satisfactory text-books is by no means easy.

It is for the above reasons that Mr. Brown is to be warmly congratulated on his volume, which should find a wide public. The amateur who is keen on extending his knowledge will find it readable and instructive, the mathematics used being simple but necessary for quantitative work. As a preliminary course for the future radio-engineer there is no volume that could be so confidently recommended, while the physicist, who, leaving awhile his more theoretical studies, wishes to know more about the subject matter of wireless will find the information very readily accessible in this volume.

The first seven chapters of the book deal with the fundamental theory of transmitting and receiving circuits and with what might be called pre-war wireless. As Mr. Brown does not give too much space to the older branches of the subject, such as spark and arc generators, he is able to devote the main body of the volume (ten chapters) to thermionic valves, radio telephony and the newer branches of the subject such as directional wireless, short wave transmission, the propagation of waves through space, and atmospherics.

Although the author obviously did not set out on the impossible task of giving an exhaustive account of all the receiving circuits now in use there is throughout the volume no dearth of diagrams which embody most directly the essentials of any particular method of reception. Indeed, in summarising the characteristics of this volume, one might say that Mr. Brown's success lies in his ability to give the essentials of any of the wireless problems dealt with, without overloading his description with extraneous matter which so often confuses the beginner. E. V. APPLETON.

Short-Wave Wireless Telegraphy.

Paper read by Mr. T. L. ECKERSLEY before the Wireless Section, I.E.E., on 2nd March, 1927.

ABSTRACT.

THE paper * deals with short-wave practice and theory, the discussion falling into four sections: 1. The aerial transmission characteristics, in particular the computation of vertical polar diagrams; 2. Results of experiments with short-wave direction finding; 3. Results of a series of long-distance transmission tests, on waves between 25 and 10 metres; 4. General theory of ionic refraction, etc.

Vertical Polar Diagrams of Transmitter.

It is important to decide whether the horizontal or vertical rays are the more effective in transmission and to design aerials which will radiate efficiently in the direction required. In previous attempts to calculate transmitter polar diagrams, it has been assumed for simplification that the earth is a perfect conductor. This may lead to considerable error, because the corrections due to the imperfect conductivity of the earth involve the product of frequency and resistivity, which may become significant at the frequencies of short waves.

The author then deals with the case of a vertical doublet A at a height h above the earth, as in Fig. 1.†

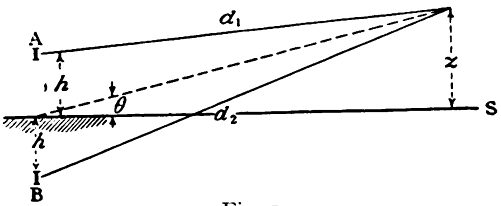

Fig. 1.

It is shown that the field at d_1 is given by the field due to A together with the effect of a negative image of A situated at a distance h below the surface of the earth, *i.e.*, it is that which would be produced by the oscillator at A together with another oscillator at B in which the current is 180° out of phase with the oscillator at A. It is also shown that there is a critical value of the angle θ above which the polar diagram is that appropriate to a perfectly conducting earth, and below which it is appropriate to a perfectly resisting earth. In general, for resistivities such as are usually found, the earth angle θ is of the order of 10° on the short-wave range, say 15 to 50 metres. Figs. 6, 7 and 8 show the calculated polar diagrams for various heights h.

The full curves represent the opposed doublets, and are appropriate for small angles. The dotted curves represent the effect of adding doublets and are appropriate for high angle transmission. The critical polarising angle is represented by the line OP at an angle θ. This angle varies with the wavelength and earth constants.

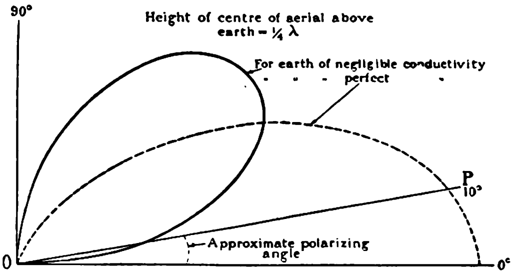

Fig. 6.

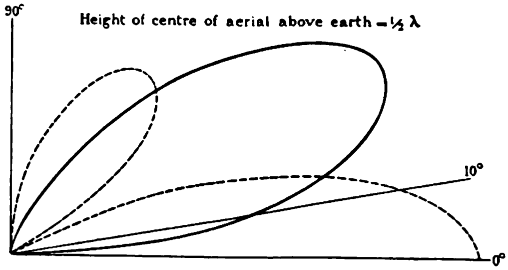

Fig. 7.

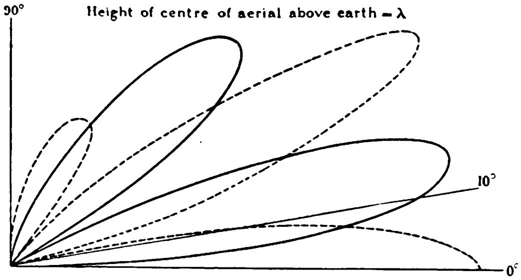

Fig. 8.

Polar diagrams for a horizontal aerial are similarly shown in Figs. 9, 10 and 11.

Since there is no polarising angle in the case of a horizontally polarised ray there is no critical angle where the polar diagram changes. It is obvious that if horizontal radiation is necessary for long-distance transmission the aerials must be raised to

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* The paper was first received on 1st December, 1926, and in final form on 21st January, 1927, and thus represents an up-to-date review of the subject of short waves.

† The Author's original figure numbers are adhered to throughout this abstract.

an height. On the other hand, for high angle transmission a half-wave aerial situated near the earth's surface is practically as good as any other.

Short-Wave Radio Direction Finding.

In the second section direction finding experiments are discussed. The circuits for a figure-of-eight diagram are shown in Figs. 12 and 13, and for

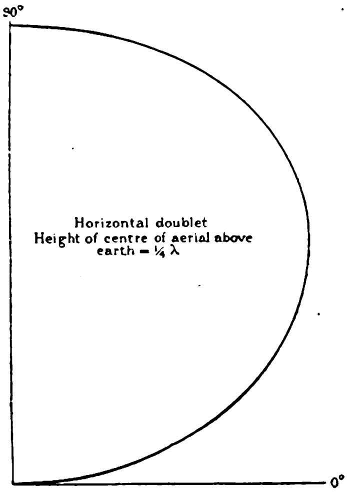

Fig. 9.

a cardioid in Fig. 14. The circuit is strictly symmetrical, and shielded as shown. Tested on local stations (distances up to a couple of miles), the arrangement gave excellent figure-of-eight diagrams with minima 180° apart. On more distant stations it was apparent that the frame alone was inadequate.

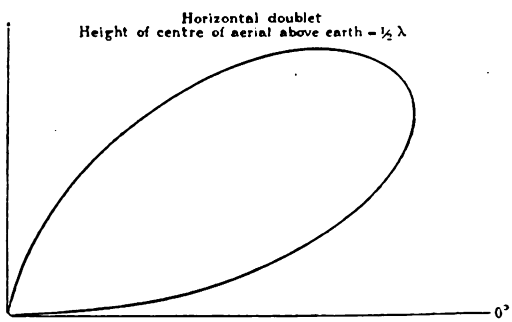

Fig. 10.

As a rule, there were no signs of minima at all, and what minimum there was from time to time varied, although giving, on a rough average, something like the correct position. It was impossible to avoid being impressed by the similarity to the conditions when bearings on longer waves suffer from "night effect." Conditions were complicated by rapid fading, so that it was difficult to tell whether a minimum was due to turning of the frame or to a fade.

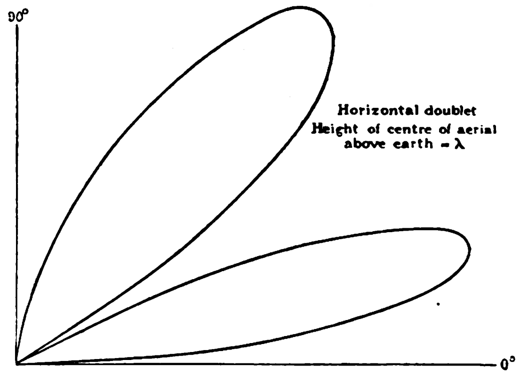

Fig. 11.

The cardioid arrangement of Fig. 14 was found to give very accurate balance on local stations. On distant stations—in particular, Nauen (AGB), Paris (FW) and an R.C.A. station in America

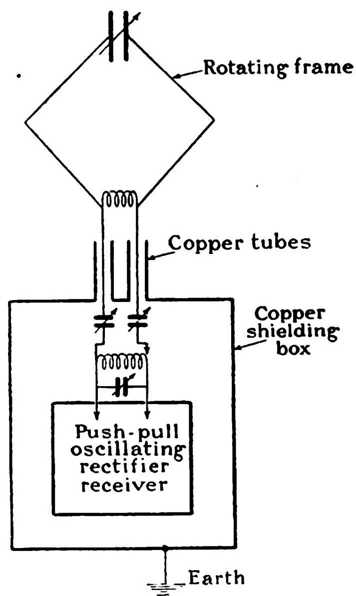

Fig. 12.

(WLL)—it was possible to obtain a fair cardioid diagram giving a minimum in approximately the right direction, and one, moreover, which did not vary.

The minima were by no means as perfect as those obtained on local stations, but were sufficiently definite and constant to permit the

inferences: (1) That the absence of minima on the frame is chiefly due to a horizontally polarised ray as in the case of long waves; (2) that the bulk of the rays follow the great circle path and strike the receiver nearly parallel to the earth's surface.

Amongst other causes it is suggested that the lack of balance may be due to a scattering of rays

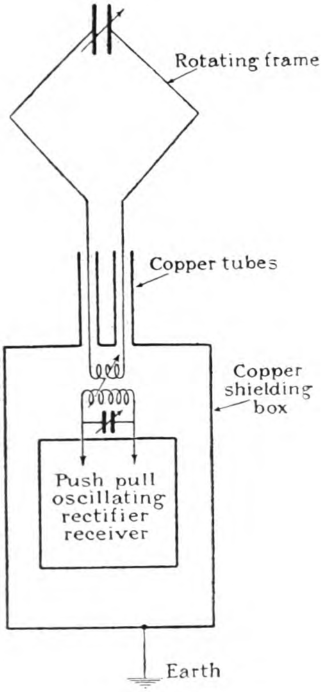

Fig. 13.

at the upper layer. In connection with scattering, it was observed that about 20.00 to 21.00 G.M.T. in July, signals from AGB were observed to fall almost to nothing, although apparently being strongly received in Buenos Ayres. The cardioid seemed to lose its characteristics, not by an increase of the signals at the minimum, but by a decrease at the maximum, suggesting that the main signal was removed leaving only scattered rays.

Examples have also been noted of signals from AGB coming by the long path round the other side of the earth, a phenomenon already described by the author in connection with work on long waves. In this case the main signal goes west with a wavering note, and following each dot or dash there is a distinct echo, which is estimated to lag about 1/7 second behind the main signal. The relative strength of signal and echo vary from time to time, and sometimes the echo has been so strong as to make the main signal practically unreadable.

With sufficient amplification it has been found possible to get the key clicks alone in which case they are doubled, with the second one following the first after an interval of about one second. The character of the second click is different, being more or less musical, in a similar manner to "squeak X's." It is suggested that this is due to a dispersion of the pulse in the ionised medium, as elsewhere suggested by the author.

The general conclusions which can be drawn from this work are more or less as follows: During the day and night the main flow of energy at distances where the direct ray is feeble is along rays which lie in the plane of the great circle joining transmitter and receiver, and these rays come in at a more or less glancing angle to the earth's surface.

The main ray is not subject to more than a slight scattering. The latter only becomes the main factor within the "jump over" distance, when the main ray skips its objective and comes down at greater distances. Fading is mostly due to the interference of the two or more rays which probably exist at distances greater than the skip distance. Signals at 14 to 26 metres may traverse practically the whole circumference of the earth at certain times and produce an echo effect. The long distance signals show evidence of the dispersive effect of the medium through which they travel.

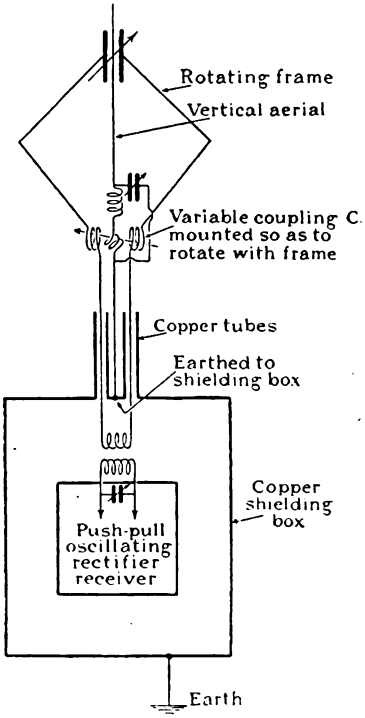

Fig. 14.

Transmission Tests.

The third section describes tests on transmission, with many curves of results under different conditions. The tests were made partly with the desire to explore the range below 25 metres, and partly to test the effect of raising the transmitting aerial. Tests were made on 24, 20, 17, 15, 13.5, 11 and 10

metres, the signals being received mainly in Sydney, Montreal, Buenos Ayres, South Africa and on S.S. *Glenamoy en route* for Hong Kong. The tests covered the period July, 1925, to May, 1926, but do not indicate the seasonal effect (except in the case of 17 metres), since the wavelength was progressively reduced during the period. The result

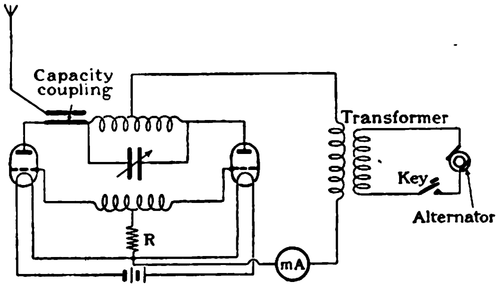

Fig. 15.

curves represent the diurnal run of signal strengths, but are not accurate measures of the signal field strengths.

At the transmitting end (Chelmsford) arrangements were made to sling a half-wave aerial on a triatic between the Chelmsford masts at a height of 80 metres, *i.e.*, approximately three wavelengths for $\lambda=25$ metres, above the ground. The original purpose was to compare the signals from this raised aerial with those from Poldhu with a low aerial. A duplicate aerial attached to a 40 foot mast on the earth's surface was also constructed with a view to making a comparison between the raised and lowered aerials. The transmitter arrangements are shown in Figs. 15 and 16. With 550 to 750 watts input it was possible to get between 2 and 3 amperes in the half wavelength aerial.

Twenty-four Metre Tests.—A typical result curve obtained at Sydney is shown in Fig. 17. These curves are similar to those obtained on long waves (15 kilometres), and there is therefore reason to believe that the causes contributing to this form are almost identical, *i.e.*, small attenuation at night and large attenuation in daytime. The peak at 20.00 G.M.T. is no doubt due to the fact that the short path (over Europe and India) is then wholly in darkness. The peak at 05.00 G.M.T., on the other hand, occurs when the long path (over Atlantic and Pacific Oceans) is almost wholly in darkness. The weaker peak at this time is naturally accounted for on this supposition for the ray path is longer and partly in daylight.

Montreal results are shown in Fig. 18, while Fig. 19 is given as a companion, showing the variation of signal strength of the Canadian beam received in Chelmsford on 1st October, 1926.

As regards results on and below 20 metres, the author states that it is difficult to generalise on the large mass of data obtained, but it is clear that in general a decrease of wavelength tends to decrease night signals and increase day signals. Thus below 17 metres there are no signals when the path is wholly in darkness. Another general fact emerges, that as the wavelength is reduced the time during which signals can be received gets less and less, and appears to tend towards the times during which the ray is wholly in the light. It is, of course, difficult to estimate the relative strengths on different waves, since the receiver characteristics are likely to control the changes, but it appears likely that below about 17 metres the maximum signal strengths obtainable decrease with the wavelength.

Twenty-Metre Tests. — These indicate an intermediate condition between all night and all day transmissions. At Sydney the chief difference between this and the 24-metre test is the increase in strength in the half light and half dark periods. This is a favourable condition, as the attenuation

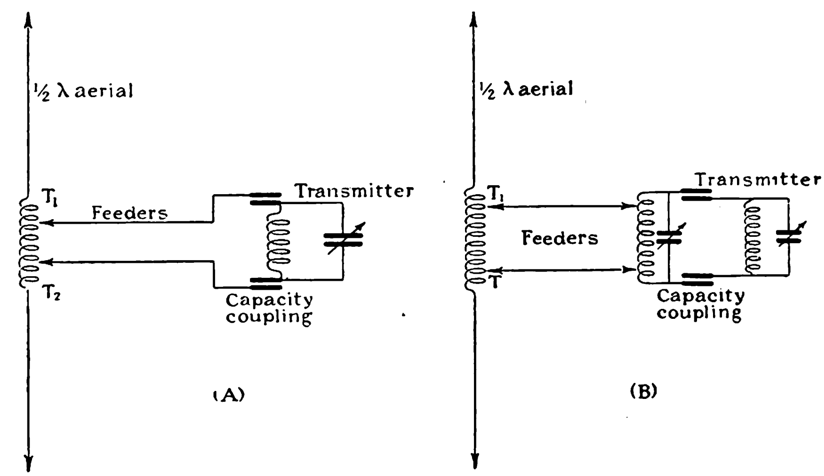

Fig. 16.

over the first half of the path in daylight is not too great, and the bending is probably greater than in the all night condition, when the total attenuation is less. At Buenos Ayres the strength is sufficient to give signals at 25 to 30 w.p.m. throughout the dark period but tails off during the half light half dark periods.

Seventeen-Metre Tests.—These were carried out at various times between 9th September, 1925, and 8th January, 1926, so that there is an indication of seasonal as well as other changes. The tendencies exhibited in the 20-metre tests are exaggerated. Thus there is an improvement in daylight transmissions and a deterioration in night transmissions.

The actual observed results imply an irreversibility in signal transmissions or a seasonal effect, implying a difference in the state of the upper atmosphere in the northern and southern hemispheres. Since seasonal effects do not appear to make any marked difference, the evidence is in favour of some irreversible effect. No direct test of this could, however, be made on account of the absence of a suitable transmitter in Australia.

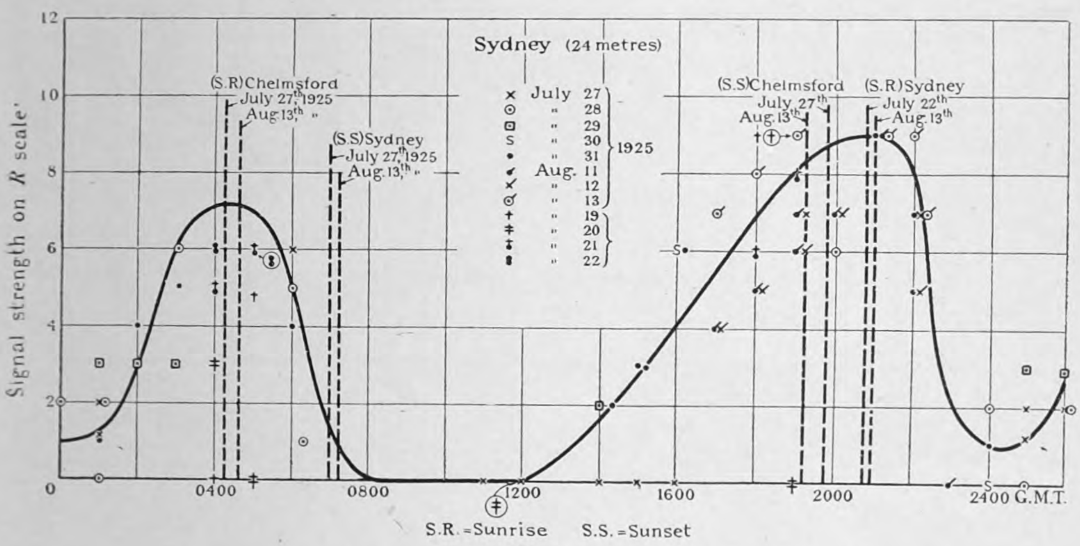

Fig. 17.

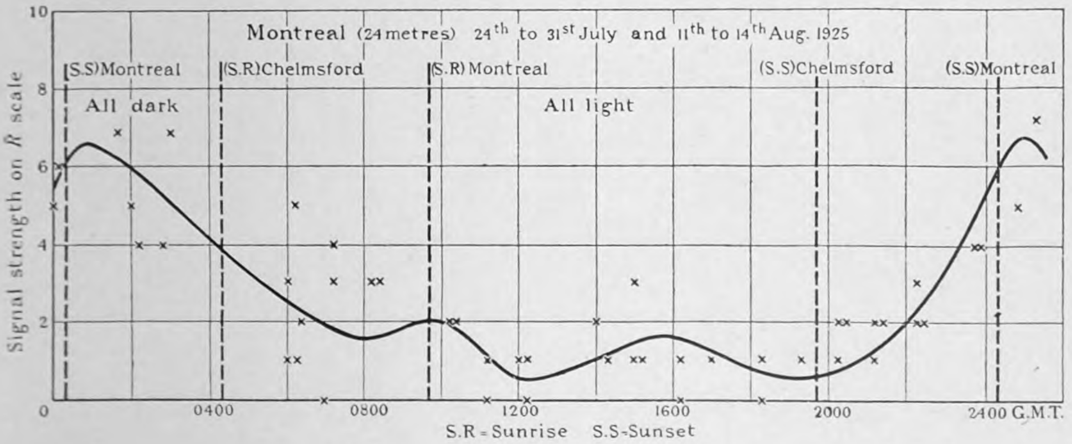

Fig. 18.

On this wavelength all day signals began to appear at Buenos Ayres. This suggests that the wavelength is so short that there is insufficient bending at night to bring down any of the rays at Buenos Ayres. This is in agreement with the fact

that all-night signals have practically disappeared in Australia on this wavelength.

Fifteen Metre Tests.—Fifteen metre tests were also carried out at various times between 15th September and 29th January. The transmission characteristics are similar to those on 17 metres, and the same argument as regards irreversibility applies on this wavelength.

Ten-Metre Tests.—Transmissions on 13.5 and on 12 metres gave characteristics generally similar to those of 15 metres. Final tests on 10 metres were made, the curve of Fig. 38 showing Australian results. Good signals were received at Buenos Ayres during the all-day light period between 12.15 and 14.40, but in later tests from 12.00 to 19.00 signals were heard only very weakly throughout the whole period. Nothing was received in Montreal.

From these tests it is concluded that all-night transmission is impossible below about 17 metres, and that the daylight range increases with decreasing wavelength.

Aerial Height Tests.—Some of the later tests also included a comparison of the transmissions from the aerial at different heights. The aerials were arranged one at an approximate height of 70 metres, another at half the height, and the third just above the surface of the earth, a mean height of about 7 metres. A very clear case of the effect of height is shown in Fig. 33, and also in Fig. 38. The author

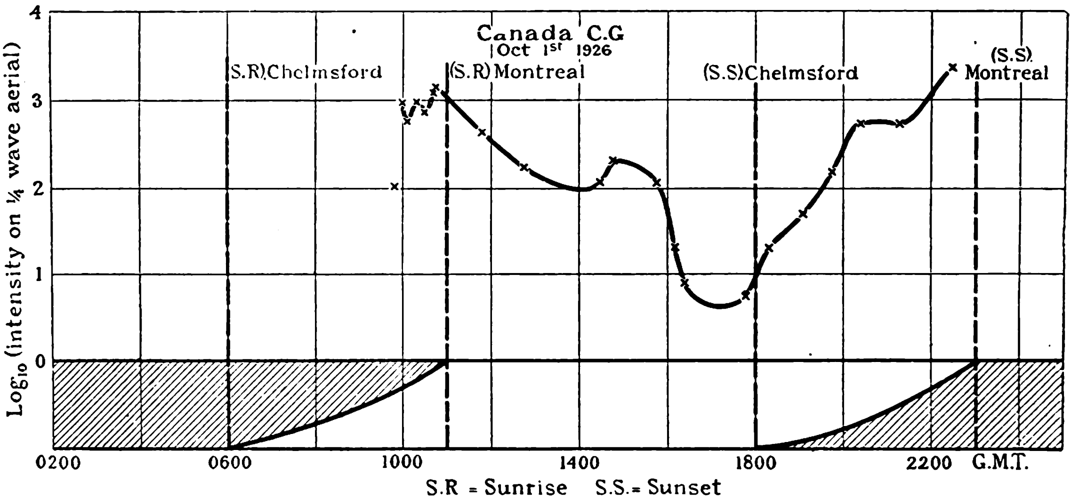

Fig. 19.

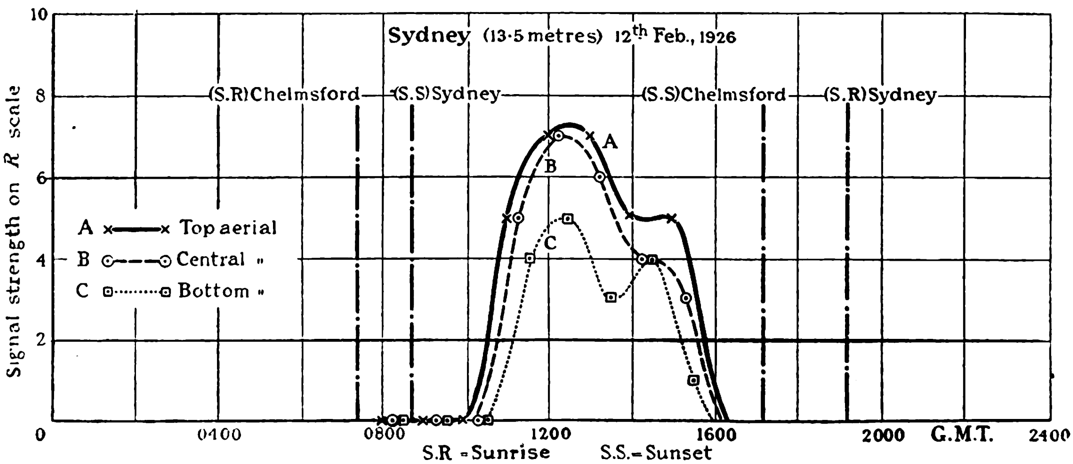

Fig. 33.

summarises that the lowest aerial is always the worst, and that there is not much difference between the two upper aerials. The contrast in strength between the upper and the lowest aerials increases as the wavelength is reduced.

the frequency. Some results from Poldhu have also been examined giving the curve of Fig. 40, which is of similar form (on log. scale of ordinate). It appears possible to the author that we are approaching the daylight limit at 10 metres, for

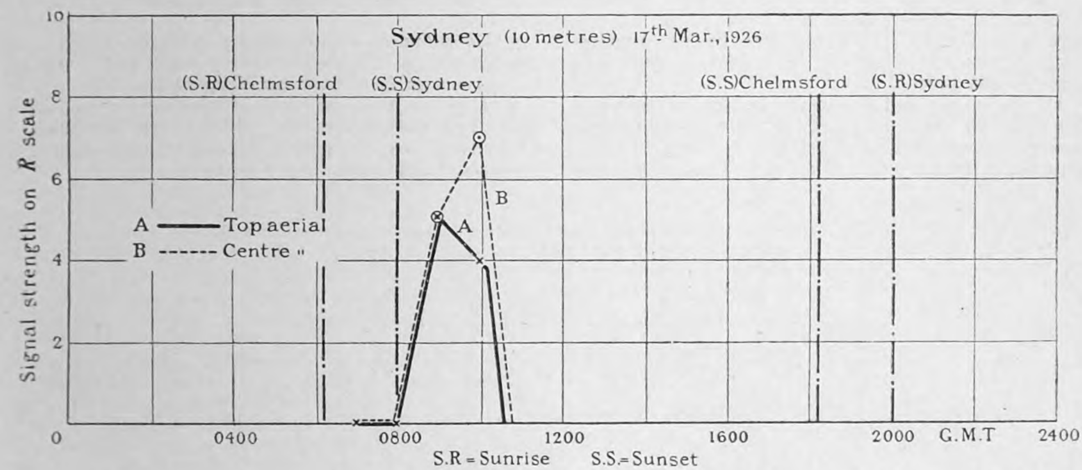

Fig. 38.

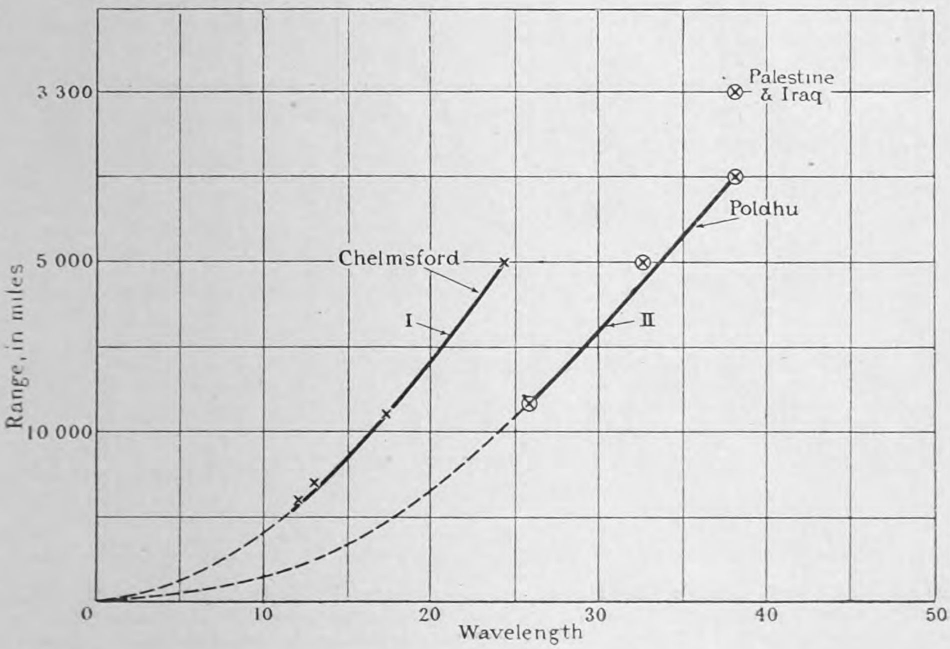

Fig. 39.

Daylight Range.—From the results obtained a rough estimate can be made of the daylight range in the region 24 to 10 metres. These are plotted in Fig. 39, where it is seen that the range increases very approximately in proportion to the square of

the signals from the lowest aerial which are projected at a fairly high angle do not appear to return to earth, or only very weakly, at Buenos Ayres, and a slight reduction in wavelength should be sufficient to cut off the rays even from the upper aerial.

Theory.

The remainder of the paper is devoted to theoretical considerations, more especially of the author's theory of attenuation in the upper atmosphere.

Losses may be attributed to three possible causes: 1. Energy lost by attenuation in the earth's surface; 2. Energy lost by attenuation in the Heaviside layer; 3. Energy lost by escape through the layer.

All the energy lost due to the last cause occurs in the first few hundred miles, and a gradual energy loss increasing with the distance is foreign to the whole idea of refractive bending. The energy lost in earth attenuation cannot be a very serious factor, as far as the author can see, except in the near neighbourhood of the transmitter and the receiver. Finally we are left with attenuation in the upper layer, which the author considers must be taken into account in building up a comprehensive theory of short wave transmission. Although the ray bending theory explains the fact that signals can be heard at the other side of the world, it fails to explain many other facts; for instance, a range proportional to f^2.

From a consideration of ray paths between two stations A and B, the author concludes that the paths are reversible, and that—

1. Absorption is the chief factor controlling the range of daylight signals.
2. The effect of raising the aerial is in general beneficial.
3. Long distance transmission is effected by rays the trajectory of which makes a small angle with the earth's surface, say, less than 20 degrees.
4. The trajectories follow great-circle paths (except possibly within the "jump over" distance, where there may be high angle reflections together with scattered radiation).

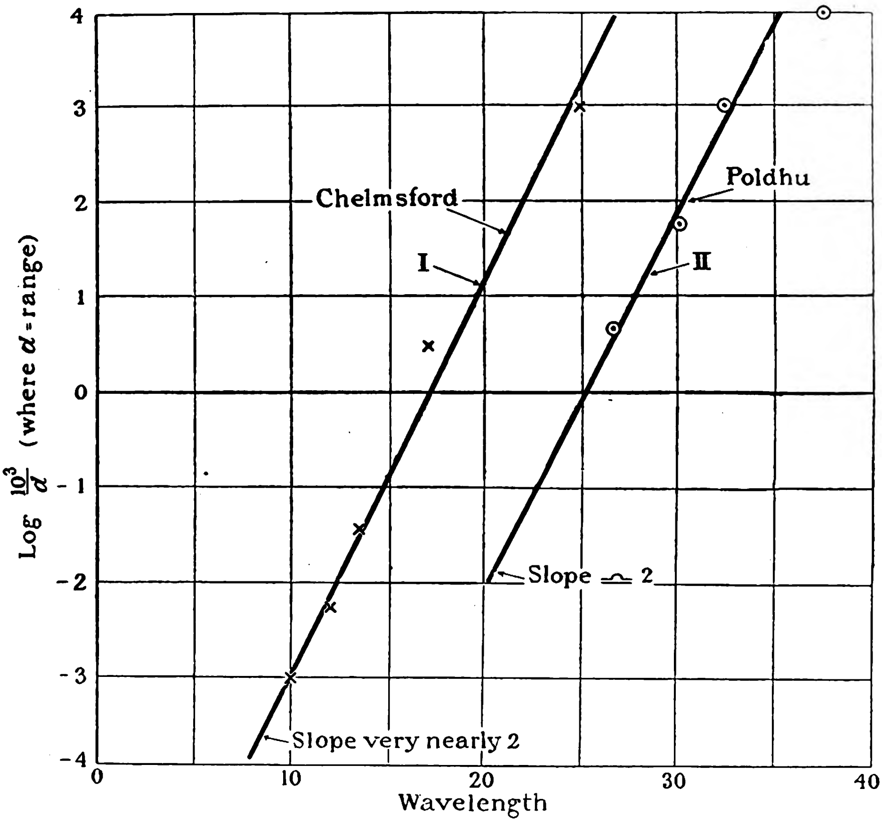

Fig. 40.

There seems little doubt that, in the main, ionic refraction is responsible for bending the short waves round the earth, but, in the author's opinion, results on this theory are largely discountenanced by the neglect of absorption.

He then proceeds to consider the loss of energy encountered at the layer, and derives an attenuation coefficient which varies inversely as the square of the frequency. It is on these grounds that the experiments which showed Range $\propto f^2$ indicate the important part played by attenuation in long

distance transmission. It should be noted that attenuation will only vary as f^2 if the ray path is the same in two transmissions. Again, since the attenuation is proportional to electronic density, it is to be expected that ionisation, and therefore density, should be greater (with increased attenuation) in summer than in winter. It is also significant that short wave transmission has been affected unfavourably in times of magnetic storms, when the ionic density is greatly increased.

He then discusses the effect of the average time between collisions (of ions in the layer), and shows that if the time period of the waves is long compared to the effective mean time between collisions the "metallic conduction" type, appropriate to long-wave transmissions, occurs. If the time period is short so that electrons or ions can execute many free oscillations before colliding with a molecule, the "dielectric" type of transmission, appropriate to short-waves, occurs, characterised by a decrease of attenuation with increasing frequency.

From these arguments a line of distinction can be drawn between long and short waves.

The author is of opinion that we may safely class all waves longer than 1,000 metres, say, as long waves and all waves shorter than 100 metres, as short-waves, that is to say, any increase of wavelength at 1,000 metres produces a corresponding decrease of attenuation, and conversely any decrease of wavelength at 100 metres produces a decrease of absorption.

The distinction between long and short waves is summed up as follows:—

Long Waves.—

Summer attenuation less than winter.

Low-latitude attenuation less than high-latitude.

Decrease of attenuation under magnetic storm conditions.

Short Waves.—

Summer attenuation greater than winter.

Low-latitude attenuation greater than high-latitude.

Increase of attenuation under magnetic storm conditions.

After a brief discussion of the various estimates of the daylight height of the layer, the author states that the preponderance of evidence seems to put it at a height of about 50 kilometres, probably varying slightly between summer and winter and in different latitudes.

As regards the night layer, its position is more definitely determined, and from consideration of the interval between collisions, the author deduces that the transmission in practically the whole of the radio range would be entirely of the dielectric type, *i.e.*, of short wave daylight type. Evidence during magnetic storms is quoted to show that night transmission on 15,000 metres is of the "dielectric" type, whereas day transmission is of the "conduction" type.

Summary of Evidence.—The general radio evidence seems to be to the effect that the refraction theory refers to short waves in which $\lambda < 100$ metres in daylight, and to practically all waves during the night. Long-wave transmission in which $\lambda > 1{,}000$ metres in daylight is characterised by metallic conduction transmission (between layers).

The author then proceeds to discuss skip distance. It is known that in the neighbourhood of a short-wave transmitter signals fall off very rapidly with distance, may disappear entirely at 100 or 200 miles, and then begin to increase again to a maximum, and finally die away at very great distances.

According to the ray theory, apart from the direct ray, nothing should be obtained within the skip distance, and there is practically a discontinuity in this region. In actual fact conditions are nothing like this.

Whatever the ratio of signals within and without the skip distance may be, the form of the Intensity/Distance curve seems to be smooth, and there is indication of high angle reflected or scattered energy within the skip distance, contrary to the ray theory. The only evidence, according to the author, is that within the skip the indirect rays (reflected or refracted) are either not present or are present with very diminished intensity.

The author again considers loss due to attenuation at the layer, and calculates the attenuation of a ray as in Fig. 47.

Fig. 47.

It is clear that the greater the angle the greater the depth of penetration, and the greater the attenuation. Again, the greater the gradient of density the shorter the path in the medium and the less the total attenuation.

The calculated values are shown in Fig. 48 (not reproduced), along with experimental results made in America, where the calculated values allowing for attenuation are seen to be in close agreement with measured values.

Short-Wave Limit.

It seems to be an undoubted fact that there is a short-wave limit below which it is impossible to get long-distance transmission.

On the evidence of the transmission experiments cited here, as well as other evidence of the same sort, it seems probable that the short-wave limit for night transmission is somewhere in the neighbourhood of 17 metres, although the echo effect seems to show that under certain conditions waves as short as 14 or 15 metres may get through 20,000 kilometres of darkness.

In daytime the short-wave limit does not seem to have been reached at 10 metres. A recent experiment on 8 metres (using the same transmitter and power as in the other short-wave experiments) seems to indicate that this is below the limit, as nothing was received in Sydney, Montreal, New York, or South Africa, so that the limit appears to lie between 8 and 10 metres. This short-wave limit has received a very natural explanation on the ray theory, *i.e.*, it is supposed that the density in the upper layer is not sufficient to bend even the horizontally transmitted rays back to earth, so that all the rays escape. The author is not inclined to accept this explanation, chiefly on the ground that there is evidence of high-angle rays, within the

skip distance, of even the shorter waves (λ 20 to 25 metres), which on the ray theory should be entirely absent.

The picture that the author has of the transmission on different wavelengths is this: For waves above the limiting wavelength this attenuation constant is small, and long-distance glancing-incidence transmission takes place in the space between this main layer and the earth. Penetration into the main layer is small, and the whole attenuation is small and caused by the sparsely populated fringe below the layer, but directly the wavelength is made shorter than this short-wave limit, and the main ray penetrates well into the main layer, absorption sets in and further long-distance transmission is impossible. This theory applies to both day and night transmission with suitable values for the average time between collisions in each case. This is essentially a modified form of layer theory.

DISCUSSION.

A lengthy discussion followed the reading of the paper.

The discussion was opened by the President of the Institution, **Dr. W. H. Eccles**, who expressed thanks for the paper. He considered that important points had been made by the author in the image of opposite phase, and in the variation of range as the square of the wavelength. As regards travel of rays round the earth, would not these be returning in all directions, and how would this affect a directional receiver in the region of the transmitter? He also sought information about the actual arrangement of the raised aerials.

Admiral of the Fleet Sir Henry Jackson expressed admiration of the author's work and treatment, and referred to the difficulties of short-wave work. He thought it would be some time before results could be checked.

Lt.-Col. A. G. Lee said he was glad of the author's suggested theories. As regards the D.F. experiments, he thought there was no proof of the absence of scatter outside the skipped distance, and was of opinion that this existed. He discussed the polar diagrams of the transmitter and the effect of the method of excitation, *e.g.*, the use of harmonics, on the angle of transmission, and finally quoted some comparisons of the beam transmissions working to Canada and Australia respectively.

Mr. J. Hollingworth spoke of the difficulty of elucidating theory. Referring to the reversibility of the ray path, suggested by the author, he did not think it should be expected that the path should be reversible. It appeared important to consider the direction of the ray with respect to the earth's magnetic field. Amongst other measurements on Rugby he had already experienced quite high angle reflection on this wavelength.

Prof. S. Chapman hoped that in time wireless transmission would add to the knowledge of the upper atmosphere. The conductivity of the layer was due to the effects of ionisation and aurora. There were many complexities in the upper atmosphere, and the author's paper was a step forward in the presentation of results.

Prof. E. V. Appleton said that the paper abounded in material to check our existing speculations. There were two ways of explaining the skipped distance. One was absorption limitation. The other was electronic limitation, *i.e.*, that there were not sufficient electrons to bend back the beam at short distances. From available data, he estimated that the density would require to be of the order of 10^7 electrons per cubic centimetre. He thought that down to 1 metre wavelength could be done without limitation due to this cause. This theory seemed to him more probable than the first, and was in agreement with the quantum theory.

Mr. R. A. Wilmotte discussed the image and the phase relations between it and the elevated aerial.

Mr. Wells considered the radiation from a vertical aerial as raised from the ground, and suggested aerial schemes to give maximum horizontal radiation.

The author briefly replied to several of the points raised in the discussion, when the Chairman, **Prof. C. L. Fortescue**, moved a vote of thanks, which was heartily accorded.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 174 *of March issue.*)

10. The Binomial Theorem.

THE Binomial Series has already been introduced. It is

$$1, mx, \frac{m(m-1)x^2}{2!}, \frac{m(m-1)(m-2)x^3}{3!} \text{ etc., etc.,}$$

the general or nth term being

$$\frac{m(m-1)(m-2)(m-3)\ldots(m-n+2)x^{n-1}}{(n-1)!}$$

The further discussion of this series will lead us to one of the most famous theorems in the whole of mathematics and certainly one of the most useful—the Binomial Theorem.

The name sounds rather impressive, and the series itself looks very complicated and mathematical; but, after all, it is only a number, or rather a set of numbers. To make sure that our feet are still on solid ground, let us materialise this airy spirit and give it a substantial form by putting $m=5$ and $x=2$. The numbers then become

$$1, 5\times2, \frac{5\times4\times4}{2} \quad \frac{5\times4\times3\times8}{3\times2}$$

$$\frac{5\times4\times3\times2\times16}{4\times3\times2} \quad \frac{5\times4\times3\times2\times1\times32}{5\times4\times3\times2}$$

i.e., $\quad 1, 10, 40, 80, 80, 32.$

There are only six terms to the series in this case, for the seventh and all subsequent terms contain the factor 0 in the numerator. The sum of the six terms is 243.

So much by way of reassurance, in case it was necessary. Now we can return to the symbols and try to find some simple formula for the sum of the series when m is a positive integer. We have already seen that in all such cases the series is finite and terminates at the $(m+1)$th term. The sum of the series is clearly a function of x and of m, so we can write

$$f(x,m) = 1+mx+\frac{m(m-1)x^2}{2!}+\frac{m(m-1)(m-2)x^3}{3!} \text{ etc., etc.}$$

Now multiply each side by $(1+x)$ and arrange the right-hand side in ascending powers of x, as in the original series. The multiplication is quite a simple and straightforward process and the reader will have no difficulty in showing that

$$\{f(x,m)\}(1+x)=1+(m+1)x+\frac{(m+1)mx^2}{2!}+\frac{(m+1)m(m-1)}{3!}x^3, \text{ etc., etc.}$$

Now the right-hand side is the original series but with $(m+1)$ written everywhere instead of m, *i.e.*, it is $f(x, 1+m)$,* so that

$$\{f(x, m)\}(1+x)=f(x, 1+m)$$

It follows from this that

$$f(x,m)=(1+x)^m$$

but it is rather a long jump so we will come to it in smaller steps. Since m is any positive integer, put

$$m+1=r.$$

Then $\quad m=r-1$

and we have $\quad (1+x)f(x,r-1)=f(x,r)$

or $\quad \dfrac{f(x,r)}{(1+x)}=f(x,r-1)$

Since this is a perfectly general formula, we may say that

$$\frac{f(x,r)}{(1+x)^2}=\frac{f(x,r-1)}{(1+x)}=f(x,r-1-1)=f(x,r-2)$$

The process can be continued, giving

$$\frac{f(x,r)}{(1+x)^3}=f(x,r-3)$$

and so on, up to r times, which will lead to

$$\frac{f(x,r)}{(1+x)^r}=f(x,r-r)=f(x,0)$$

But $\quad f(x,0)=1$

---

* To make this entirely complete and convincing it should be proved for the general term in each case. This can be done but is a rather lengthy business. The reader should be able to do it for himself.

Therefore $$\frac{f(x,r)}{(1+x)^r} = 1$$

so that

$$(1+x)^r = f(x,r) = 1 + rx + \frac{r(r-1)x^2}{2!} + \frac{r(r-1)(r-2)x^3}{3!} \text{ etc., etc.}$$

which is what we set out to prove. The symbol m has got changed on the way, but that doesn't matter.

If $m=5$ and $x=2$, the sum of the series is therefore $(1+2)^5=3^5=243$, a result which has already been demonstrated above.

So much for positive integral values of m; but the series is not inherently limited in the values that m may take, so it will be necessary to carry the investigation one stage further and find what the series means when m is negative or fractional.

It has already been shown that in such cases the series is infinite, and that it is convergent when x is less than 1 numerically, which condition will be assumed in all that follows.

Without assuming anything at all about u and v, take the two binomial series

$$f(x,u) = 1 + ux + \frac{u(u-1)x^2}{2!} + \frac{u(u-1)(u-2)x^3}{3!} \text{ etc., etc.}$$

$$f(x,v) = 1 + vx + \frac{v(v-1)x^2}{2!} + \frac{v(v-1)(v-2)x^3}{3!} \text{ etc., etc.}$$

multiply them together, and arrange the product in ascending powers of x. As before, the operation should really be carried out for the general term, but this would take rather too much of our limited space. Taking any finite number of terms the reader will have no difficulty in showing that the product can be put in the form

$$\begin{aligned} &f(x,u)\,f(x,v) \\ &= 1 + (u+v)x + \frac{(u+v)(u+v-1)x^2}{2!} + \frac{(u+v)(u+v-1)(u+v-2)x^3}{3!} \text{ etc., etc.} \\ &= f(x,u+v) \end{aligned}$$

This is the important step, and the full interpretation of the series is implicit in this equation, for we can use it to show that

$$f(x,m) = (1+x)^m$$

even when m is negative or fractional, provided x is less than 1 numerically.

Suppose first that u is a positive integer, and that v is a negative integer equal to u in magnitude (*i.e.*, $v=-u$). Then since

$$f(x,u) = (1+x)^u$$

u being a positive integer, and since it has been shown that

$$f(x,u)\,f(x,v) = f(x,u+v)$$

for any values of u and v, then if $v=-u$,

$$\begin{aligned} f(x,u)\,f(x,v) &= (1+x)^u f(x,-u) \\ &= f(x,u+v) = f(x,u-u) = f(x,0) \end{aligned}$$

But $$f(x,0) = 1$$

Therefore $$(1+x)^u f(x,-u) = 1$$

or $$f(x,-u) = 1/(1+x)^u = (1+x)^{-u}$$

which establishes the result for a negative value of m.

From the general result

$$f(x,u)\,f(x,v) = f(x,u+v)$$

it is easy to show (as on p. 560 in the issue of *E.W. & W.E.* for September, 1926) that

$$\{f(x,u)\}^q = f(x,uq)$$

where u has any value, and q is a positive integer.

Since u can have any value, let it be a fraction p/q, so that uq is a positive integer p. Then the equation

$$\{f(x,u)\}^q = f(x,uq)$$

becomes

$$\{f(x,p/q)\}^p = f(x,p) = (1+x)^p$$

Therefore (see p. 561, September 1926)

$$f(x,p/q) = (1+x)^{p/q}$$

which proves the result for a fractional index.

To sum up,

$$(1+x)^m = 1 + mx + \frac{m(m-1)x^2}{2!} + \frac{m(m-1)(m-2)x^3}{3!} + \text{etc., etc.,} + \frac{m(m-1)(m-2)\ldots(m-n+2)x^{n-1}}{n-1!} \ldots$$

for all values of x if m is a positive integer,

and for all values of m provided x is less than 1 numerically. This is known as the Binomial Theorem.

It is obvious that there are many useful and important applications for this result. Take for instance the general solution of a quadratic equation :—

$$x=\frac{-b\pm\sqrt{b^2-4ac}}{2a}$$

which can be put in the form

$$x=\frac{-b}{2a}\left\{1\mp\left(1-\frac{4ac}{b^2}\right)^{\frac{1}{2}}\right\}$$

Now if $4ac$ is less than b^2 numerically, so that $b^2/4ac$ is less than 1 numerically, putting $x=-4ac/b^2$ and $m=\frac{1}{2}$ in the Binomial expansion gives

$$\left(1-\frac{4ac}{b^2}\right)^{\frac{1}{2}}$$

$$=1-\frac{2ac}{b^2}-\frac{2a^2c^2}{b^4}-\frac{4a^3c^3}{b^6}-\frac{10a^4c^4}{b^8}-$$

etc., etc., *ad. inf.*

so that the solutions are

$$x=-\frac{b}{2a}\pm\frac{b}{2a}\mp\frac{c}{b}\mp\frac{ac^2}{b^3}\mp\frac{2a^2c^3}{b^5}\mp\frac{5a^3c^4}{b^7}$$

etc., etc., *ad. inf.*

In terms of actual numerical values this series solution may not be any simpler for computation than the original form of solution, but since the successive terms will decrease in magnitude more or less rapidly according to the magnitude of $4ac/b^2$, this form of statement facilitates a process of approximation, and if $4ac/b^2$ is very small compared with 1, so that powers above the second can be neglected, it gives a very closely approximate solution in a very simple form.

Again, the binominal theorem is very useful for the approximate calculation of certain numerical expressions. The nth root of a number, for instance, can be obtained by a general method which can best be explained by a simple illustration. Find to four places of decimals the fifth root of 3031. First find by guessing and trial the nearest whole number—in this case it is 5, for $5^5=3025$. Then

$$3031=5^5+6=5^5(1+6/3025).$$

Notice as a further simplification that

$$6/3025=6/5^5=6\times 2^5/10^5=6\times 32/10^5$$

Then $\sqrt[5]{3031}=5(1+6\times 32\times 10^{-5})^{\frac{1}{5}}$

$$=5\left\{1+\frac{6\times 32\times 10^{-5}}{5}\right.$$

$$\left.-\frac{4\times 6^2\times 32^2\times 10^{-10}}{25\times 2}+\text{etc., etc.}\right\}$$

$$=5(1+.00038)$$

taking the first two terms only. (A little consideration will show that the third term will not affect the fourth place of decimals.) Finally

$$\sqrt[5]{3031}=5.0019.$$

Certain power calculations can be very considerably simplified in a similar manner, *e.g.*, $(3.03)^{10}$. This can be put in the form

$$(3.03)^{10}=3^{10}(1+10^{-2})^{10}$$

$$=3^{10}(1+10\times 10^{-2}+45\times 10^{-4}$$
$$+120\times 10^{-6}+210\times 10^{-8}\text{ etc., etc.})$$

$$3^{10}\times(1.10462)$$

$$59049\times 1.10462$$

correct to five figures. The last multiplication will be a rather long business but the whole calculation will be very much shorter than the direct working out of the original expression.

Apart from these immediate and practical uses the Binomial Theorem plays a large part in the development of other important series. This is illustrated in the Exponential Series, of which mention has been made already in the preceding instalment.

11. The Exponential Series.

It has been shown that the series of numbers

$$1,\ x,\ \frac{x^2}{2!},\ \frac{x^3}{3!},\ \frac{x^4}{4!},\ \frac{x^5}{5!}\ \ldots\ \frac{x^{n-1}}{(n-1)!}$$

known as the Exponential Series, is convergent for all values of x. The series is really a special case of the Binomial Series, and can be derived in this way.

$$\left(1+\frac{1}{n}\right)^{nx}=1+\frac{nx}{n}+\frac{nx(nx-1)}{2!\ n^2}$$

$$+\frac{nx(nx-1)(nx-2)}{3!\ n^3}+\text{etc., etc.}$$

$$=1+x+\frac{x(x-1/n)}{2!}$$

$$+\frac{x(x-1/n)(x-2/n)}{3!}+\text{etc., etc.}$$

Now by sufficiently increasing n, the series on the right can be made to differ by as little as we please from the series

$$1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \text{etc., etc., } ad.\ inf.$$

In other words, this series is the limit of the original series when n tends to infinity, and we have

$$\underset{n\to\infty}{lt.}\left(1+\frac{1}{n}\right)^{nx}=1+x+\frac{x^2}{2!}+\frac{x^3}{3!}+\frac{x^4}{4!}\ \cdots$$
$$+\frac{x^{n-1}}{(n-1)!}\ \cdots \text{ etc., etc., } ad.\,inf.$$

(This, by the way, though it is given in this form in some text-books, cannot be regarded as a rigid proof. The limit of the sum of an infinite number of quantities is *not necessarily* the same as the sum of their limits, as the above proof assumes. However, it serves to demonstrate the connection between the Binomial and the Exponential Series. A completely rigid proof would take rather more space than can be allowed to it.)

An important special case of this series is that in which $x=1$. The series then becomes

$$\underset{n\to\infty}{lt.}\left(1+\frac{1}{n}\right)^{n}=1+1+\frac{1}{2!}+\frac{1}{3!}+\frac{1}{4!}+\ \cdots$$
$$+\frac{1}{(n-1)!}\ \cdots \text{ etc., etc., } ad.\ inf.$$

The number represented by the series on the right-hand side plays a very large part in physics, particularly in electricity. It is called ϵ, and its magnitude to ten places of decimals is 2.7182818285. Readers have already made the acquaintance of this number in the section dealing with logarithms where it was introduced as the base of the system of Naperian or Natural Logarithms. It was remarked at the time that nothing could seem more arbitrary and unnatural than this awkward looking number, but we see now that there is at least nothing arbitrary about it, and a little further consideration will show that there is very good reason for calling it "natural." The reason is that it symbolises a process of growth or change which is of very frequent occurrence in natural phenomena.

Consider, for instance, what happens when a condenser of capacity C is given a charge of amount Q_0 and then allowed to discharge through a resistance R as shown in Fig. 16. The charge on the positive plate of the condenser will flow away in the form of a current through the resistance, and the magnitude of this current will depend on the potential of the condenser, *i.e.*, on the charge on the condenser. Thus the condenser discharges at a rate which is proportional to the charge, or, in other words, the charge disappears at a rate which is proportional to itself. This means that the rate of discharge will not be constant for any finite interval of time, but decreases continually as the charge leaks away. The determination of the charge left on the condenser after any given interval thus appears to be a very difficult matter. In fact, it cannot be solved directly without the aid of the Differential Calculus. The following method can be made to give the right answer, however, and is a very good example of the part played by ϵ in all such phenomena.

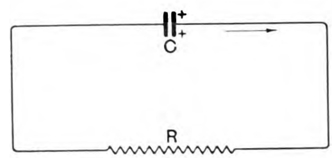

Fig. 16.

We will assume that the rate of discharge varies not continuously, but by sudden steps. That is, we will assume that the condenser discharges for an interval of time δt at the rate corresponding to the initial conditions, and then for a second interval δt it discharges at the rate corresponding to the conditions at the end of the first interval, and so on. The initial potential of the condenser is Q_0/C, and the initial current is therefore this potential divided by the resistance, *i.e.*, Q_0/CR. Since a current is the rate of flow of electricity, the quantity of electricity that leaves the condenser at this rate in the time δt is $Q_0\delta t/CR$, and the charge left on the condenser at the end of the first interval (call it Q_1) is $Q_0 - Q_0\delta t/CR$, *i.e.*,

$$Q_1 = Q_0 - Q_0\delta t/CR = Q_0(1 - \delta t/CR).$$

Similarly, Q_1 being the charge at the beginning of the second interval, the charge at the end of the second interval will be

$$Q_2 = Q_1(1 - \delta t/CR) = Q_0(1 - \delta t/CR)^2$$

and so on. After n such intervals the charge will be

$$Q_n = Q_0(1 - \delta t/CR)^n.$$

Assuming that we want to determine the charge after an interval t we can consider that this interval is divided up into n smaller intervals δt, *i.e.*, $t = n\delta t$, and writing Q_t for this remaining charge

$$Q_t = Q_0(1 - \delta t/CR)^n = Q_0(1 - t/nCR)^n$$

But this is admittedly an approximate solution. The rate of discharge does not remain constant during the interval δt, however short that interval may be; but it is clear that the shorter the interval, the more correct the solution will be. That is, for a given interval t, the larger n becomes the more nearly correct will be the solution. In fact the approximation can be made as close as we please by sufficiently increasing n, and the exact solution is therefore the limit of the above expression when n tends to infinity, *i.e.*,

$$Q_t = Q_o \underset{n\to\infty}{lt.} (1 - t/nCR)^n$$

This can also be written

$$Q_t = Q_o \underset{n\to\infty}{lt.} \{(1 - t/nCR)^{-nCR/t}\}^{-t/CR}$$

and, writing $1/m$ for $-t/nCR$ (notice that m and n will tend to infinity together)

$$Q_t = Q_o \underset{m\to\infty}{lt.} \{(1 + 1/m)^m\}^{-t/CR}$$

$$= Q_o\ \varepsilon^{-t/CR}$$

The reader should put in some actual values in order to get some idea of the scale of the phenomenon. How long will it take the condenser to discharge completely, that is, for what value of t is $Q_o\ \varepsilon^{-t/CR}$ zero? The answer is that there is no finite value for t which makes Q_t zero. The condenser is *never* discharged. Think of it! All the condensers in the world are still trying to get rid of their last charge and not succeeding. Actually, of course, the charge falls to an immeasurably small quantity in a very short time, fractions of a second in general, and can be made smaller than any given quantity by making t sufficiently large. Mathematically speaking complete discharge of the condenser is represented by

$$\underset{t\to\infty}{lt.}\ Q_t = \underset{t\to\infty}{lt.}\ Q_o\ \varepsilon^{-t/CR} = 0$$

Nature abounds in instances similar to the above, where a quantity changes at a rate which is proportional to the magnitude of the quantity. In all such cases ε, generally with a negative index, will appear in the mathematical representation of the process. In fact ε turns up nearly as often as π, which is saying a good deal. An instance of special interest to readers of this journal is one which the writer was the first to publish as far as he is aware. The grid current of any ordinary small receiving valve for negative values of the grid voltage can be represented very closely by a curve having the equation

$$i_g = a\ \varepsilon^{bv_g}$$

(See *E.W. & W.E.*, November 1925, p. 867 *et seq.*). This can be taken as showing that the emission must involve in some way a change which occurs at a rate proportional to the magnitude of the quantity that changes.

Conclusion of Part I.

So much by way of an introduction to Algebra (for even at the risk of discouraging the reader it is well to remind him that it is only a bucketful out of the ocean; but it should prove sufficient for most of the practical requirements of readers of this journal). The writer can only hope that a fair proportion of readers have found it to be what they were needing. The only published comment has been favourable, and one Continental wireless paper has thought the articles worth translating and reproducing in full, but the writer does not flatter himself that everyone has been pleased. To parody an historic phrase—he may have pleased some readers all the time and all readers some of the time, but certainly not all the readers all the time.

One final word of advice will not be out of place before we leave this part of the subject and proceed on the next stage of the journey towards the calculus. Mathematics, like mankind, is a mystic duality of body and soul. Algebra is the soul of arithmetic. Its intimate association with, and, in a certain sense, dependence upon, concrete reality should never be forgotten. A comprehensible numerical or physical interpretation is the ultimate sanction of any algebraical operation, and only within the limits of this sanction can the wonderful labour and thought-saving devices of

algebraic symbolism be employed with perfect confidence. Even practised mathematicians are liable to be pulled up short by the sudden materialisation of a grinning absurdity out of a mist of ill-defined symbols, as when, for instance, to quote an example that recently came to the writer's notice, a few pages of apparently unimpeachable analysis led to the conclusion that the height of the Heaviside layer could be expressed as a complex number. As the Duchess would have said to Alice, the moral of that is,—take care of your grounds, and the sense will take care of itself.

Examples.—Binomial and Exponential Series.

1. Expand to the first five terms
   (a) $1/(1+x)$
   (b) $1/(a^5-x^5)^k$
   (c) $(1-x)^{-3}$

2. Show that the nth terms of $(1-x)^{-n}$ and $(1+x)^{2n-2}$ are equal.

3. Find $6\sqrt{719}$ to four places of decimals by the Binomial Theorem. (Note.—$3^6=729$.)

4. Find $7\sqrt{108}$ to four places of decimals by the Binomial Theorem. (Note.—$2^7=128$.)

5. Show that

$$a^x = 1 + x\,log_e a + \frac{x^2(log_e a)^2}{2\,!} + \frac{x^3(log_e a)^3}{3\,!} + \text{etc., etc., } ad.\ inf.$$

(Note.—Put $a = e^m$, *i.e.*, $m = log_e a$.)

6. Show that

$$\frac{e^x+e^{-x}}{2} = 1 + \frac{x^2}{2\,!} + \frac{x^4}{4\,!} + \frac{x^6}{6\,!} + \frac{x^8}{8\,!} \text{ etc., etc., } ad.\ inf.$$

$$\frac{e^x-e^{-x}}{2} = x + \frac{x^3}{3\,!} + \frac{x^5}{5\,!} + \frac{x^7}{7\,!} + \frac{x^9}{9\,!} \text{ etc., etc., } ad.\ inf.$$

7. Show that

$$\frac{1}{e} = \frac{2}{3\,!} + \frac{4}{5\,!} + \frac{6}{7\,!} + \frac{8}{9\,!} + \text{etc., etc., } ad.\ inf.$$

Answers to Examples in March Issue.

1. The $(n+1)th$ term is $an+a+b$. Therefore $(n+1)th$ term $-nth$ term$=a$, which is constant. First term is $(a+b)$. Sum of second fifty terms is $3775a+50b$.

3. If sum of n terms is $a(r^n-1)$, the sum of $(n-1)$ terms is $a(r^{n-1}-1)$. Therefore the nth term is $a(r^n-r^{n-1})$. Therefore $(n-1)th$ term is $a(r^{n-1}-r^{n-2})$, and the ratio of nth term to $(n-1)th$ term is r (const.).

4. If the nth term is ar^{n-1}, the sum of all subsequent terms is $ar^n/(1-r)$. Ratio of nth term to sum of subsequent terms is $(1-r)/r$.

5. Convergent by comparison with series $1/n$. If x is r^2 the rth term is infinite.

6. Divergent for all values of x, by comparison with $1/n$ series.

7. Divergent, by comparison with $1/n$ series.

8. Ratio of $(n+1)th$ term to nth term is $(2n+3)x/(3n+4)$, therefore series is convergent if x is less than $3/2$ numerically.

Phototelegraphy.

A Lecture and Demonstration before the Radio Society of Great Britain by T. THORNE-BAKER, M.I.R.E., F.Inst.P., F.R.P.S., delivered at the Institution of Technical Engineers, on Wednesday, 23rd February, 1927.

IT is a great pleasure to me to accept the invitation to come and show these instruments at work and also to give an account, in a brief way, of the work of a very large number of men who have taken part, in this country and elsewhere, in bringing the problem of phototelegraphy to maturity, because this branch of work has now reached a certain stage of maturity. Their work has led up to phototelegraphy and the transmission of images, writings, etc., as it is to-day. I have been associated with picture-telegraphy since 1907, just over 20 years. In 1907 I went over to Paris to study the subject with Professor Korn, who was one of the colleagues of Professor Rontgen, and it has been my good fortune during those 20 years to come into contact with almost everyone who has been concerned with this development. Therefore, I want to let you see in the right perspective the part that each of these people have played, because all their systems are the germs of the systems in use to-day, and I think you will find it is a matter of instrumentation and adaptation to modern telegraphic work, modern physics, and modern radiotelegraphy that has just bridged over the gulf between the old experiments and some of the excellent transmissions we have to-day.

I would first like to show you a slide (not reproduced*) which is familiar; it is the ordinary coloured photograph of the spectrum, beginning at the blue end with waves about $400\mu\mu$† through the various colours running up into the extreme red, which is about $800\mu\mu$.

In the next slide (showing the relationship between the visible band of frequencies and the entire range of known ether oscillations) the small range of radiation of the visible spectrum is shown. If you take the shortest *gamma* rays emitted by radium, the wavelength of which is about half an Angström unit, and you pass through X-rays and the ultra-violet rays, you come to the visible range of colour from red to violet, and then on through the infra red into the wireless radiations which may run up to the large dimensions of miles-long waves that are being used at stations like Bordeaux. The point of interest is that we are only turning one unit into another, that we are dealing with a picture which reflects more or less light radiation, *i.e.*, visible radiation of 400 to $800\mu\mu$. You are merely employing exactly the same type of ether motion converted into an enormously greater wave-length in order to carry these shades of light and dark to a distant station where they are reconstructed into visible light gradations by suitable mechanism.

There are various ways of using this light energy. It is quite obvious that if you want to transmit a picture made up of certain light parts, dark parts and grey parts, and you have to make an exchange with these tones or densities into a wireless signal of either long or short period, or of large or small amplitude, proportional to the tones of the picture, you need to make use of some light sensitive substance in order to absorb the light energy.

I have here a slide (view of light operated apparatus, not reproduced) showing one of the practical ways in which light is used. There are two small glass elliptical-shaped vessels one of which is black and the other is white. There is a little ether in both, and the light rays are absorbed by the blackened substance. The ether is thereby warmed and distils over; the balance is upset and the thing goes over to the other angle. It is a system which has been developed by Messrs. Chance Bros. of Birmingham, and is used in a large number of lighthouses to control the switching on and off of the light automatically by the energy of the light.

* Space does not permit of the reproduction of all of the slides accompanying the paper. This slide, and several others which illustrate well-known scientific facts, have been omitted as well as certain of the slides showing transmitted pictures in which the line or dot formations of the image would be lost in the photomechanical process used for reproduction.

† $\mu\mu = 10^{-7}$cm.

As you know, the name of the selenium cell is almost synonymous with phototelegraphy. The sensitiveness to light of selenium was discovered as you know by Shelford Bidwell. This extraordinary element, just warmed to a critical temperature of 207 degrees C., goes through an allotropic modification and becomes somewhat crystalline, and in that form it is extraordinarily sensitive to light, though its resistance is enormous. Two spirals of flattened wire are wound round a plate of steatite ; these are dusted over with selenium, which is then melted, and the " cell " is put into an oven and annealed. By just flashing an eight-candle-power lamp at a distance of about one foot on to a cell of this type it is possible to reduce its resistance from possibly 500,000 to about 10,000 ohms. The light is able to change the resistance of the cell in this extraordinary way, and you can see how the idea was suggested to the early experimenters to take a transparent photograph on celluloid, wind it round a glass cylinder with a light in the middle, and by making use of the variation of the resistance of the cell, according to the light and dark parts of the picture, to get a picture transmitted and modulated in conformity with the tones of the original. Selenium was found a great deal too slow, because when you suddenly reduce the light, its resistance does not increase sufficiently fast. There is thus a considerable amount of " lag," and you will see how in these little machines which I am going too demonstrate that lag has been eliminated. The selenium cell, therefore, except for the simplest types of picture, is out of the question.

The latest type of photoelectric cell in its simplest form is an exhausted bulb on one side of which is deposited a little metallic potassium, sodium or rubidium, which is turned into the hydride. A little argon is then introduced into the bulb. There is a quartz window to allow ultra-violet rays from the source of light to strike the metal, and there is a ring anode. When the potassium hydride is influenced by light, a stream of electrons is given off and is collected by the anode. The cell can be used as a grid-leak. It is possible, with the photographic cylinder which is giving out small amounts of light of varying intensity, to arrange a method of transmission, and the photoelectric cell seems at present to be the " be all and end all " of phototelegraphic work, although I think we shall hear quite a lot more about selenium in the course of a year or two. This cell was invented by Mr. Zworykin, in the United States, and besides being a photoelectric cell, it has the advantage of being a valve as well, so that the feeble current of 10^{-13} amperes is amplified by 10,000 or 100,000 times. The great difficulty with the selenium cell is the excessively small amount of current, which means you have to submit it to very large amplification before you can use it in a practical way.

Fig. 1. *Half-tone picture greatly magnified.*

To come now to mechanical methods of transmission. This slide (Fig. 1) illustrates an ordinary half-tone photograph such as you see in any newspaper, very much enlarged. It is composed, as you see, of dots of large and small diameter, the dark parts of the picture being made up of dots of large diameter and the light parts of dots of small diameter. If you take a piece of this photograph and enlarge it still more (Fig. 2), you will see that some dots are square and some are round. You can really divide these dots into half-a-dozen different sizes, comparable to the dots and dashes of the morse code, except that instead of either a dot and a

dash, you have dots of several different sizes. If you take a half-tone photograph and are prepared to sit up over it for two or three nights—and this has been done a good many times—you can, by studying these dots with a magnifying glass, write out a

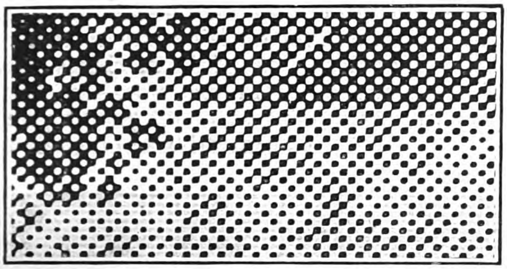

Fig. 2. *Still further enlarged piece of half-tone image, showing how the diameters of the dots are comparable with a morse signalling system.*

telegram describing the consecutive dots in order of diameter. This telegram can be sent by wire or wireless. With the aid of a piece of squared paper the picture is reproduced by filling in the squares more or less according to the letters in the telegram. This is a very laborious process. I once sat

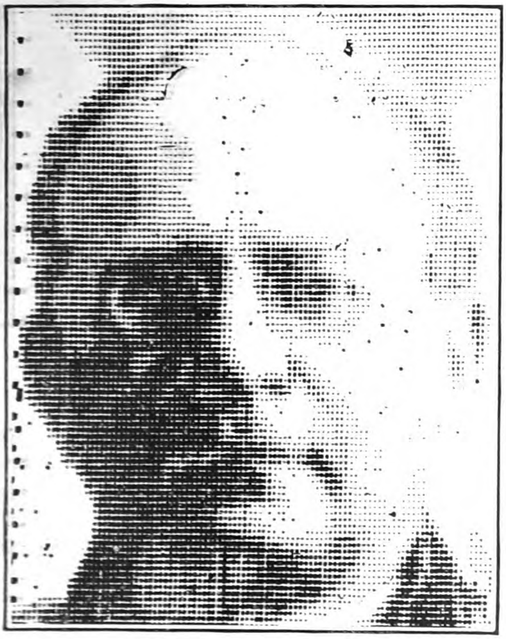

Fig. 3. *A "code" picture sent by Korn from the U.S. to Rome by wireless telegram.*

through a day and night with a Chinaman who came over here to demonstrate this system to a London newspaper, but after he had got a plausibly good photograph from America I almost broke his heart by showing him that the thing had been done 25 years before. It is one of the oldest ideas of phototelegraphy, and is due to Mr. William Gamble, the well-known photoengraving expert. To show you how this "code" method can be done, I will show you a photograph transmitted from New York to Rome by this system. (Fig. 3.) There are only three sizes of dots in this case, *a*, *b* and *c*. Professor Korn invented a sort of decoding apparatus, and he took his telegram and worked on a typewriter for two or three hours and built up the picture. This is one of

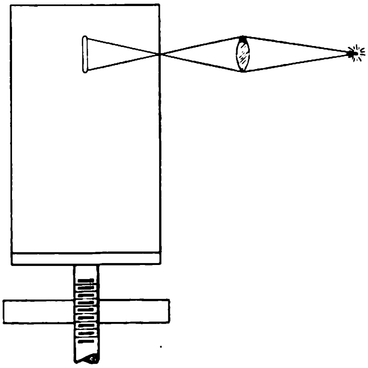

Fig. 4. *Principle of the Korn transmitter, with selenium cell within the glass cylinder.*

the first wireless photographs transmitted, and is, in fact, the only one I have seen transmitted by the code method.

We will now go on to 1905 or 1906 and see by a diagram how the method in which the selenium cell is used came into practice. A photographic film wrapped round a glass cylinder was rotated by an electric motor, a spiral shaft being used so that as the cylinder revolved it rose up and the spot of light passed through the photograph in a spiral fashion. (Fig. 4.) Thus, as the cylinder was turning and rising, this spot of light would explore the whole of the photograph, bit by bit. The light was passed on to a selenium cell, so that as dark parts of the picture passed before the rays the cell was altered in resistance, and so on.

The current fluctuations were applied to a telephone line between London and Paris,

the received current being passed through a string galvanometer of the Einthoven type. (Fig. 5.) The string or ribbon moves in a magnetic field, and for small currents the displacement of the string is directly proportional to the current, so that the tones of the photograph will be faithfully recorded. There is a

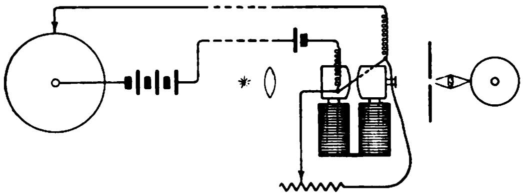

Fig. 5. *Korn's telautograph. The photographic film for reception is mounted on the small cylinder in a dark chamber.*

Nernst lamp and a lens, and a beam of light passes through a hole in the poles of the magnet and through a slit, and is focused on to the photographic film in a dark chamber. According to whether the tones in the photograph are light or dark so the current is greater or smaller, the string acting as a shutter, allowing more or less light to fall upon the sensitive film.

The silver string is represented in Fig. 6. It was not quite large enough, so finally Korn employed two silver wires $\frac{1}{1000}$ inch diameter, with a little magnesium shutter $\frac{1}{30}$ inch square to cut off the light.

This is the first photograph (a portrait of King Edward) sent with Professor Korn's apparatus from Paris to London in 1907. Owing to the receiving cylinder running too fast, we unfortunately lost a portion of the King's head. The synchronism has

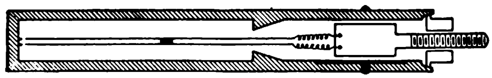

Fig. 6. *The magnesium shutter on parallel strings, as used in Korn's galvanometer.*

to be of an accuracy of about half per cent., otherwise an elongation of the face results.

This is another photograph (Fig. 7) of a lady who was claimed to be at that time the prettiest girl in Paris. You will see that the dark lines have widened a little, showing that the mechanism of the shutter has been shifted slightly with the increases in current, allowing a wider beam of light to affect the film. I regard Professor Korn as one of the greatest pioneers in commercial phototelegraphy.

Now I come to the important question of synchronisation. The transmitting and receiving cylinders must run at nearly identical speeds, an elementary fact which must be admitted when first devising any system of phototelegraphy. Most of the machines were driven—some of them are now—by high speed motors running at about 3,000 r.p.m., geared down by a worm drive in oil so as to

Fig. 7. *News portrait transmitted from Paris to London.*

run the actual cylinder one revolution in three to five seconds. In order to get the motors at each end running approximately at the same rate, frequency meters are used, working from slip rings fitted to the motors giving alternating current. A small variation from 97 periods to 103 periods gives a range of 3 per cent. either way. Actually you have to keep within a half per cent. accuracy and make up for any losses in the running rate at

the end of each revolution. Fig. 8 gives an idea of the synchronising apparatus. The receiving cylinder is always run at a higher rate than the transmitting cylinder, and is stopped at the end of every revolution by a little check

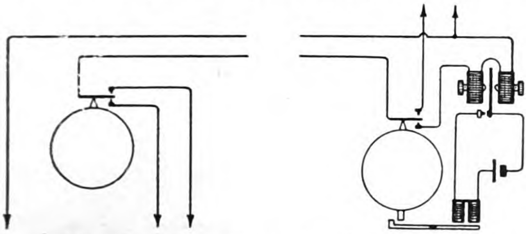

Fig. 8. *Scheme of synchronisation. The transmitter is on the left.*

which works against a catch. The transmitting drum, which is running slower, works at the end of each revolution a reverse-current contact, which in turn operates a polarised relay. That relay throws in another magnet, which draws away the check, and the result is that however much the two cylinders may be out of step in one revolution, they are bound to start off at the beginning of the next revolution at exactly the same instant. How we have got over the synchronising of two instruments not connected with wires will be seen when I start the wireless machines up later on.

Now we come to a mechanical method of picture transmission which is of great interest, and that is the Belin method, of which I am quite sure you have heard a great deal. You may remember that M. Belin was

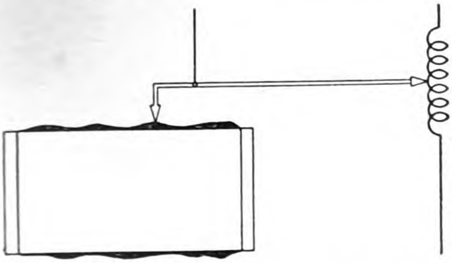

Fig. 9. *Belin's relief method in principle.*

over here a year or two ago giving a lecture at the Royal Society of Arts. He and Professor Tschörner have both worked out processes in which the image to be transmitted is in relief. Those of you who are photographers will know the carbon process, in which a photographic print is made in gelatine. It is washed with hot water after exposure and all the gelatine which has not had sufficient exposure to light remains soluble and is washed away. When the print is made you get it in relief, the dark parts being raised.

If you can imagine the view shown in Fig. 9 to represent a section of one of these carbon photographs, there is a little stylus riding over the surface, and as the cylinder turns round, the hills and dales of the relief picture come round and raise the stylus up and down, operating a rheostat through which the telegraphic current is passing. It is not quite as simple as that in actual practice, however. Belin's first idea was to have a little wheel which ran over a rheostat made up like a commutator, but he finally

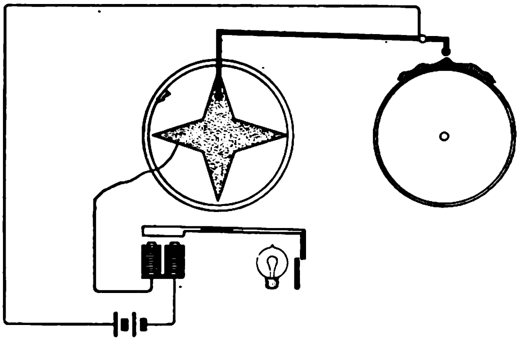

Fig. 10. *Tschörner's relief method.*

abandoned that and now he uses a special form of microphone, the pressure due to the varying thickness of the picture operating the microphone. In this case he uses an alternating telephonic current which acts as a carrier.

Tschörner's method is somewhat similar. He gets the motion by means of a metal star (Fig. 10) which is put on to a fibre disc and turns in conjunction with the cylinder. As this needle is raised and lowered, so the point on the star gets higher or lower, and as you see it gives a longer period contact or a shorter one. Therefore, whilst Belin gets a varying amplified current, Tschörner gets a difference in period in consecutive signals.

It is rather interesting to consider some of these early pictures of 1906, because it is just as well that some of us who might think

we are now doing rather well should be reminded of the remarkably good things that were done 20 years ago.

Now we are going a little farther back still, to the days of Casselli, because his transmitter is used by me and by a number of other people. It is used by the Telefunken people, by Dr. Alexanderson of the General Electric Co. of America, and was also used

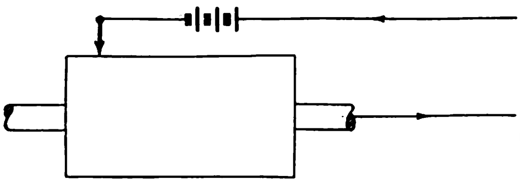

Fig. 11. *Diagram of the Casselli transmitter.*

by Korn in making his first attempts at transmitting half-tone photographs. It is a plain cylinder (Fig. 11) with a plain gramophone needle or stylus, and it is just a make-and-break process, similar to a morse key in result. You have an electric current passing through the drum, which is generally earthed in the case of telegraphy, and from the stylus is the wire going to the distant station. If you fold a piece of tin or copper foil round the cylinder upon which is written or drawn a sketch in some kind of insulating ink, then as the insulating lines pass under the needle the circuit will be broken and the interruptions of the current can be made to operate a relay at the other end of the line and record the signals either photographically or mechanically. Professor Korn used the Casselli transmitter with one of his string galvanometers.

We now come to the method that I have adopted for sending wireless pictures by broadcast. This photograph (Fig. 12) consists of thick or thin lines, wide lines for dark parts, and fine lines for light ones. If you take any photograph and put it on a copy-board and photograph it through a screen with diamond lines ruled 50 or 60 to the inch, you get a negative in which the photograph is broken up into parallel lines of varying thickness according to the brightness or darkness of the particular part of the picture. You can print these pictures in fish glue, which is highly insulating, on copper foil. These line pictures are then simply slipped over the Casselli cylinder, the current is switched on and the transmitter acts as a morse key. The advantage is, however, that it is truly photographic and you have currents varying in duration. You would think, perhaps, that there are only about half-a-dozen different widths of line, but careful microscopic examination shows that you can count up to 30 or 40 widths with the eye, and there must be many more actually that you cannot differentiate, but which actually come into photographic reproduction by this method.

This shows the first photograph (not suitable for reproduction owing to the nature of the screen) I sent with my original machine from Manchester to London. It is a photograph of the first lady councillor in Liverpool, and you will notice how the mouth and the eyebrow have been put out of shape, as well as the collar. These things are simply due to lack of proper synchronism. The motors

[*By courtesy of Bell Telephone Co.*]

Fig. 12. *Formation of a "line" half-tone image.*

ran a little too fast, but generally in those days these defects were not removed to make people realise that the pictures had actually been telegraphed. Many people thought them fakes at the time.

I am now going to pay a tribute to the two

American systems of which we are hearing a good deal. This is a photograph taken (of good definition and resembling an ordinary half-tone illustration) by the Bell system, which is operated over telephone lines, and synchronised by alternating current synchronous motors. The photoelectric cell is employed here, and one of the men who was responsible for this admirable process is Mr. Herbert Ives, whose name I do not think is so well known in the electrical world as it is in connection with photography, and that is important because successful picture telegraphy is not a subject which can be tackled only by the electrical engineer. It wants the co-operation of the process man, it wants the electrical engineer and also the telegraph man, but it wants, above all, the photographer. The Bell telephone system involves a number of valves to amplify up the very feeble current of the photoelectric cell, and precautions are taken to use only the straight line characteristics of the valves. There are a thousand machines employing the Bell system of phototelegraphy under construction for America.

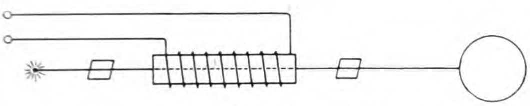

Fig. 13. *Rignoux and Fournier's nicol prism and carbon disulphide receiver.*

This is another receiving system which I should like to show because it is an ingenious and easy one. (Fig. 13.) Two nicol prisms are so displaced that the light is plane polarised through the first prism, and then passes through a tube to the second prism, where it is completely polarised. It is well known that when the electric current passes through a coil and exerts a magnetic field around certain liquids, the plane of polarisation is altered. When the current passes through the spiral, the effect of the rotation of the plane of polarisation is to alter the illumination. This system, which was devised many years ago by Rignoux and Fournier, has been adopted in one of the new phototelegraphic systems, of which we are likely to hear a good deal more before long.

I want now to refer to the Ranger method of reception. A photoelectric cell is used for transmission, but in reception there is an inkpot and pen, which taps a spot of ink on a sheet of paper and the received image is built up in that way. Very great difficulty was experienced in finding an ink which would set quickly enough not to smear. A wax ink was employed, and now an ink holder is used in which an electric heater is placed to keep the wax melted. The moment the pen taps a spot of the ink on to the paper it sets. It took many months before the problem of obtaining the right ink was solved. I only mention this because there are many details in working out these apparently simple systems, and a matter like this of the ink, although so trifling to the onlooker, had the effect of keeping the invention back for months.

A portrait of President Coolidge transmitted by the system is shown in Fig. 14. All the dots in this system are the same size, but in my system and most other systems the dots or signals vary in size according to the tones in the picture. It is a very peculiar thing how effective is the result in the case

Fig. 14. *A picture transmitted on the Ranger system from New York to London.*

of the Ranger system, because theoretically such results should not be obtained. With dots all of the same size it is surprising that a half-tone effect should result. However, it does so very effectively.

up a picture. This paper is put on a cylinder and every time the gramophone needle of the sender comes into contact with a clear part of the picture to be sent, actually between the fish glue lines, it gives a signal

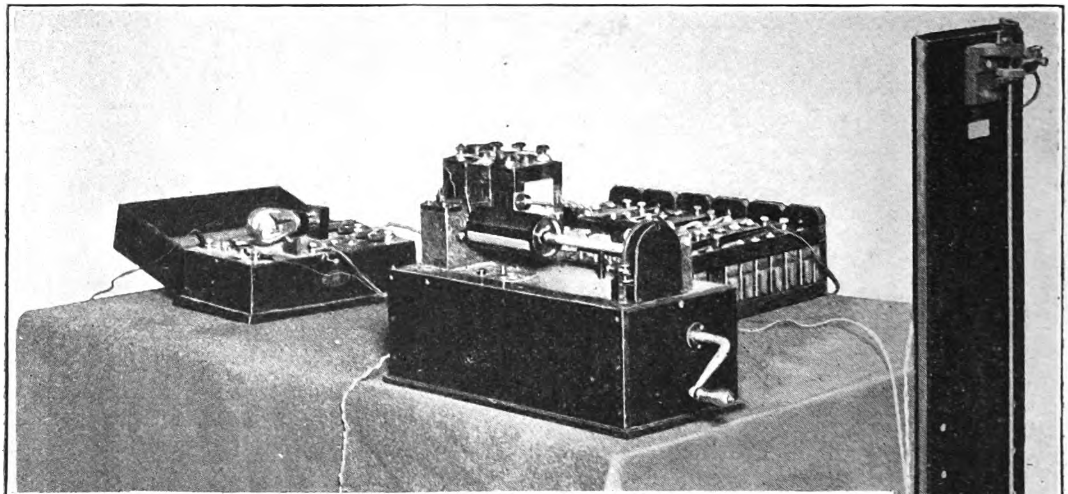
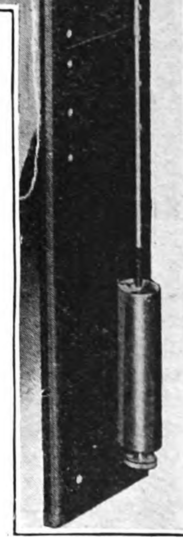

Fig. 15. *The transmitting apparatus.*

Having completed his list of lantern slides, Mr. THORNE - BAKER continued : These little machines of mine (Figs. 15 and 16) have been designed on general lines which have long been known. There is no originality in the system as a system. It is the type which I hope will be available in Austria shortly for receiving broadcast photographs. It comprises a brass cylinder, a holder with the gramophone needle, a special form of clockwork motor, wound up like a gramophone, a spiral shaft and a steel knife edge. As the shaft drives the cylinder, this knife edge travels across and brings the stylus with it, and in this way the spiral motion of the shaft over the surface of the picture is obtained. I use for receiving a piece of chemical paper very like pole-finding paper, although I am sure I spent more time finding it than the man who discovered pole-finding paper ! The point is that it is excessively sensitive. It is used slightly damp and 0.5mA will give a perfectly satisfactory result at the rate of 500 signals per second, so that with 1/500th of a second and so small a current as half a milliampere current you get a satisfactory mark with which to build which is picked up by the radio receiving set and operates it direct. There is no mechanical relaying. It is amplified by valves, and that gives sufficient current for the platinum needle attached to the receiving cylinder to produce the chemical stains which build up the image, so that you can watch the actual reproduction of the picture. I have arranged for several photographs to be sent across the hall, so that you can watch the building up of the image on the receiver. I think you will then appreciate how simple it is.

I will take the opportunity of saying that with the exception of one very great advance made by my colleague, Captain Otto Fulton, which does away with the pendulum for synchronising the machines, and which therefore makes the system much simpler for the amateur, the machines are exactly

as they have been for the past 18 months. A large number of most successful demonstrations have been given with the apparatus, yet I have found it absolutely impossible to get any pictures broadcast in this country, although every amateur who has seen the machine at work seems to be intensely interested, and many hundreds of people have asked where they can buy the apparatus. There is no point in making the receiving apparatus available if there are to be no pictures broadcast, and it seems to me rather sad that Austria is going to be the first country to operate this machine. As soon as the necessary arrangements are completed, three pictures a night are to be broadcast by the Ravag in Vienna. It is only through the work of my colleague, Captain Fulton, who has been over to Vienna and given demonstrations, that we have been able to get the Vienna broadcast people to start, and I hope a little later on we shall be able to do something here.

A picture (Fig. 17) was then transmitted wirelessly across the hall of the Institution of Electrical Engineers although at one time the lecturer was compelled to ask the audience not to crowd round the receiver as the capacity effects of their bodies rendered some of the signals difficult of reception and broken lines resulted.

A series of questions were asked Mr. Thorne-Baker at the conclusion of the lecture. We give the questions *seriatim* with Mr. Thorne-Baker's replies.

Question : What is the solution used for the paper ?

Mr. THORNE-BAKER : The solution is starch-iodide. The starch is a particular type which gives a permanent image. Ordinary starch solution is very unsatisfactory because the picture fades almost immediately.

Question : Is there any reason why the period of vibration of the pendulum should not be speeded up to get a picture more quickly ?

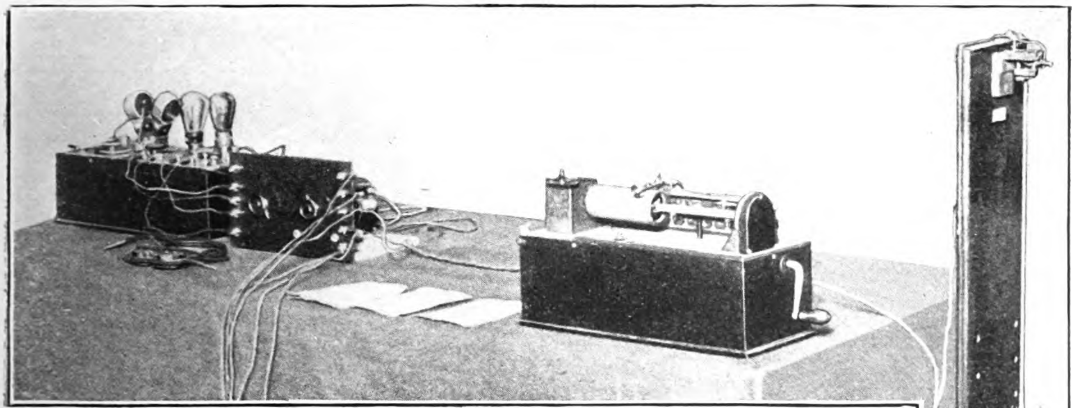
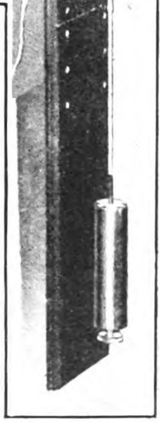

Fig. 16. *The receiving apparatus.*

Mr. THORNE-BAKER : With a $6\frac{1}{2}$ in. by $4\frac{3}{4}$ in. photograph we are recording 375 signals per second, but it is not so much the receiving as in the transmission that the difficulty arises of speeding up. The fish glue lines are rather apt to make a gramophone needle "chatter," and it does not then respond to the exact distances between lines of varying width. I remember some years ago making these transmitting foils of tinfoil and clamping them between steel plates under high pressure to get a sort of smooth commutator surface, but even then there was a distinct limit to the rate at which the needle will pick up signals with sufficient accuracy to record the proper width of line.

Question : Do you think it would be possible to adapt this machine to an ordinary gramophone, with a disc instead of a cylinder ? I suppose this apparatus is not expensive and for an ordinary amateur transmitter would it be possible to adapt it to the gramophone ?

Mr. THORNE-BAKER : It would be for a series of photographs, otherwise you would have a nasty hole in the centre of the picture. That is the mechanical difficulty. There is one rather interesting point in connection with that. Captain Fulton has for some time been working on a flat

receiver which could be operated from one of these cylinder machines and the latest development in that way is to make the flat plate a sort of lantern slide of an epidiascope and the image can be thrown on a lantern screen so that an audience can watch the picture coming. I hope it will be possible to demonstrate that in two or three months' time.

Question : I should like some information on the subject of the patent of Hardy in 1923 in regard to selenium, which he claimed to be a considerable advance. It reminds one of the old tinfoil condenser construction but I have not any further details. I should be glad to know what kind of speed one can get with such a cell or is there any more rapid type ?

Mr. THORNE-BAKER : I do not know of any more rapid method than the selenium cell method of Korn in which two cells with complementary characteristics are used on each side of a Wheatstone Bridge. You can get 50 to 60 signals per second with that arrangement. On the other hand, it is very difficult to understand how in the case of selenium cells for recording music you can get up to as many as 8,000 signals per second. I did some work some years ago with an American in connection with a talking cinematograph, in which he was recording sound on a moving band of cinematograph film, using a selenium cell. We got exquisite reproductions, except that we marred it by dynamo vibrations. Yet in phototelegraphy it has not been possible to get more than 50 or 60 signals per second. I think it is because in recording a picture you have to go over the whole range of intensity of illumination of the selenium cell whereas in reproducing the voice you are using just the peaks of the curves and you do not get the blur as you do in pictures.

Question : Has the cathode ray oscillograph been developed into picture writing to any extent ?

Mr. THORNE-BAKER : Yes, it is being used by Belin and Dauvillier in Paris for television, but television is rather a difficult subject to discuss and I would rather not say anything about it.

Question : Is the electron discharge in the photoelectric cell proportional to the amount of light passing ?

Mr. THORNE-BAKER : Yes, provided there is no inert gas in it it is absolutely proportional to the intensity of the light. There is no time lag. At any rate, the response is under a millionth of a second with the photoelectric cell. But you can easily get two milliamperes through a selenium cell, and only 10^{-13} milliamperes from a photoelectric cell of this type.

Question : What about capacity effects ?

Mr. THORNE-BAKER : If the capacity effect is too great one signal will lag into the next and you will get a continuous tone for the whole picture.

Question : The capacity of the ordinary line from London to Paris is considerable and would presumably have some effect ?

Mr. THORNE BAKER : Yes, but you get over it by the usual telegraphic tricks of reverse or "wiping out" currents and so on.

Fig. 17. *A reproduction of the actual picture transmitted during the demonstration using the Thorne-Baker apparatus.*

Television.

The following contribution to the discussion of a paper by Mr. J. L. Baird before the Radio Society of Great Britain, which was published in our December issue, has been received from Mr. Dénes von Mihály, of Hungary.

During the past two years various articles describing Mr. Baird's experiments in Television have appeared in different publications, from which it would appear that he is actively engaged in the problem of television. As I have also been deeply absorbed in this problem for the last fourteen years, these articles have been of great interest to me.

Almost every day fresh reports concerning television are published, some of which may be taken seriously, whilst others are merely amusing. In any case there is an indication that this problem is engaging universal attention, and a keen desire to see expectations materialise is widely entertained.

The newspaper articles concerning Mr. Baird's work, savouring more of propaganda than science, and presenting picturesque visions of the future rather than technical details, have made it impossible for me to judge the value of his work.

In the December issue of *E.W. & W.E.* (pages 730 to 737) there is, however, published a paper read before the Radio Society of Great Britain. The paper is of a technical nature, and as it is headed by the name of Mr. J. L. Baird, I presume that he was responsible for its preparation.

In his introduction he makes a comparison between television and the working of the human eye which tallies exactly with the words written on the subject in *The Handbook of Phototelegraphy and Teleautography*, by Korn and Glatzel (Nemnich, Leipzig, 1911). The conclusions, however, which he draws concerning the action of visual purple are fundamentally wrong, for otherwise he would never have attempted to prepare a light sensitive cell of this substance. The disintegration of visual purple is indeed like an electro-chemical process, but in character approaches far more that of a photographic plate. The valuable research work of v. Kriess has gone to prove that visual purple does not recuperate, but must be continually generated anew, and this process, as is well known, can hardly be imitated. Also the process is an organic chemical one and requires a comparatively long time—one-eighth of a second—for its completion. The human eye is, therefore, slow in its response, and it is due to this fact alone that the transmission of pictures, such as by cinematography and television, becomes possible. It is obvious that were it possible to reproduce this organic substance, and by its use to influence electrical circuits, it would at least be as sluggish in its operation as the eye itself.

* [D. v. Mihály is one of the leading European authorities on the subject. The second edition of his book, *Das Elektrische Fernsehen*, was reviewed in our February number.—Ed.]

The apparatus which Mr. Baird employs for analysing the picture comprises discs which are provided with various slits, intercrossing each other, and through which light from single small points of the picture are successively allowed to pass. This device presents nothing essentially new, for it is almost exactly the same as proposed by Brillionin in 1891 and again by Majorana in 1894, only to be rejected by them as quite unsuited for practical purposes. Apparatus of this nature only serves to demonstrate the principle and is satisfactory only so long as one is content with a transmission of 60 to 100 spots of light. But if we wish to transmit a picture measuring only 10 cm. by 10 cm. and to divide it into areas of only 1 square millimetre we find that this already means 10,000 light spot elements per picture. To transmit the 10,000 light spots within the time period of the inertia of the human eye, which is about one-tenth of a second, we must divide up the picture into 100 strips and each strip must be again crosswise or diagonally divided into 100 sections within the brief period of time of one-tenth of a second.

The first division of the image into strips is usually termed the "primary analysis" and the cross-wise subdivision the "secondary analysis." The primary analysis presents no difficulty and is accomplished by means of a disc which is provided with a slit, which in rotating traverses the picture every tenth of a second. Using a single slit, as in Mr. Baird's apparatus, this disc would have to make 600 revolutions a minute, but if one takes a disc with 10 slits then 60 revolutions a minute will suffice, but the diameter of the disc in this case must be ten times as great.

The secondary analysis, however, presents serious difficulties. It is obvious that, as the primary slit is making a movement of 1 millimetre across the face of the image, it must be crossed over by a secondary slit subdividing it into 100 sections. If the picture is 10 centimetres, *i.e.*, 100 millimetres, wide, then the primary slit will occupy 100 positions. In each position a transversal secondary slit must pass, *i.e.*, 100 secondary slits within one-tenth of a second. These secondary slits must be arranged around the edge of a second analysing disc in such a manner that between each successive slit there is a space corresponding to the height of the picture, so that two light spots do not simultaneously pass through. This circumstance gives rise to a very difficult problem of construction, even with the above-mentioned most primitive demands. In the case of a picture 10×10 centimetres, if one has, as indicated in Mr. Baird's drawing, 50 secondary slits on the disc, it is obvious that its circumference must be fifty times 10 centimetres, making the diameter of this disc about $5\frac{1}{4}$ feet.

Now in order to allow 100 secondary slits to intersect in every tenth of a second, this secondary disc would have to rotate twice in that time, that is, 1,200 times a second. If, on the other hand, the disc is provided with only 10 slits, one would have to contend with a disagreeably high speed of rotation. As in any case the stability of the disc is very much impaired by the slits near the edge, it hardly seems advisable to revert to such a high speed of rotation.

This, then, is the case with a primitive minimum of only 10,000 picture elements. I would, however, draw attention to the fact that the poorest newspaper blocks have a screen which represents a division of three points per millimetre. Therefore, in order to produce a result which has any practical value, we require, not 10,000 picture elements as suggested by Mr. Baird, but at least 90,000.

Another shortcoming appears to be the fact that the slits in the revolving discs being narrow and one behind the other, occasion an enormous loss of light.

Further, I am of opinion that Mr. Baird's movable set of lenses, even with only 16 lenses, presents the most formidable manufacturing difficulties inasmuch as the lenses must " keep the track " with optical exactitude. An insurmountable obstacle is raised with the question as to how the number of these lenses can be increased to meet practical requirements.

Now, I would like to mention briefly one of the most important of all television problems about which Mr. Baird makes no statement. It is in the matter of synchronisation. He must not forget that in practice the transmitter and receiver discs are completely separated from one another, and yet must rotate in such absolute synchronism that within the period of one second, a variation of one-hundred-thousandth of a revolution must not occur. This means that his picture analysers must synchronise to one-hundred-thousandth part of a second and must do this without connection by wire.

And here I must refer to a curious statement on his part (page 735, line 29) that "this fluctuating current is transmitted to the receiving station *by wire* or by wireless."

I should regard this extraordinary assertion as an oversight were it not for the fact that two lines further on he states " at the receiving station the current is amplified by a three-valve *low* frequency amplifier."

Every well-versed wireless amateur knows that in the case of long distance transmission, the higher speech frequencies (harmonic oscillations, character oscillations of 12,000 to 14,000 per second) cause enormous difficulties, and when one has to deal with over 20,000 impulses to the second, transmission becomes impossible.

Mr. Baird will actually require to transmit, as a minimum, at an oscillation frequency of 100,000 and yet he makes the suggestion of amplifying the current impulses at the receiving station by means of a low frequency amplifier. That he is not thinking of high frequency wire transmission follows from the fact that he speaks of amplifying by means of a *low* frequency amplifier.

What Mr. Baird represents as an important problem, viz., the necessary artificial illumination of the person to be transmitted is not pertinent, though, of course, the person whose image is to be transmitted should not be subjected to the disagreeable warmth produced by the close proximity of incandescent lamps. Actually, one of the approved methods of lighting, such as is employed, in the production of cinematograph pictures, may be adopted, and suitable light sensitive cells employed. According to determinations which I have carried out, the sensitiveness of such cells when used with an intensity of light, such as is adopted for the taking of cinematograph films, proves to be ample.

And here I would like to add a few words about invisible rays. It may be known to Mr. Baird that in the year 1890 Pontois discovered that all light sensitive cells are influenced just as much by direct or reflected infra red rays as they are by ordinary light rays. During the past 37 years this discovery has been confirmed by hundreds of those who have been engaged in scientific research work. That these infra red rays can be projected or reflected in the same way as ordinary light rays is well known.

In view of the considerable amount of publicity which has been given to Mr. Baird's work and the far-reaching importance of television to civilisation generally, I think it only fair in his own interests, as well as in those of the public and technically interested persons, that he shou d be good enough to give his observations on the problems I have raised.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

That Audio-Frequency Problem.

To the Editor, E.W. & W.E.

SIR,—In the current issue of *E.W. & W.E.*, Mr. E. Fowler Clark proceeds to clear up the question of the audio-frequency transformer, but I am afraid that in a "rather lengthy contribution" he simply begs the question.

His statements relative to the transformer may be correct, but are not the questions at issue, for the discussion was originally, not the design of the most efficient transformer, but as to whether the maximum amplification attainable with a valve plus transformer is given with a transformer having an impedance equal to that of the valve, or is given when the transformer has an impedance much greater than that of the valve?

Mr. Fowler Clark's statements Nos. 1, 2, and 3, do not seem to lead up to or explain his statement No. 4, which is the only one in which he mentions transformer plus valve. The two must be taken into consideration together, otherwise the line of reasoning is useless.

It would be much more to the point if we could have the "definitely erroneous" part of the "recent advertisements" explained. As Mr. Albert Hall pointed out, this little portion of mathematics does not apply to the last or output stage where one requires power, but at intermediate stages where voltage amplification is needed, surely it is better to have the largest portion of the impedance drop—if I may use the expression—of the valve plus transformer primary circuit occur across the transformer primary to be transformed up on to the grid circuit rather than have only half the available impedance volts applied to the primary and the remaining half wasted across the valve impedance.

I wonder what a power-transformer designer would have to say to Mr. Fowler Clark's remarks that, presumably in order to obtain maximum secondary volts, one has to use as many volt-amperes as possible. From my knowledge of transformer design, the amperes taken by the primary when the secondary is on open circuit are kept down to the minimum if the transformer has to work on open circuit for a length of time which is large compared with its "on load" periods, and the secondary voltage is dependent —neglecting losses—only upon the primary voltage and the step up. Therefore one must use the maximum possible primary volts and a suitable step-up ratio.

In conclusion I would like to add that increasing the primary impedance a long way towards its technical limit in laboratory experiments does improve results from the intervalve transformer and valve combination which, to me at any rate, goes a long way to proving its correctness.

T. R. LUPTON,
M.Sc.(Tech.).

"Delineation of A.C. Wave Forms."

To the Editor, E.W. & W.E.

SIR,—The analysis of the Lissajous figure on p. 18 is not correct. For the position *OP* of the tune vector, the length *pM* is transferred to

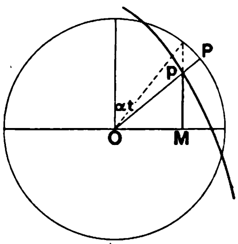

Fig. 5.

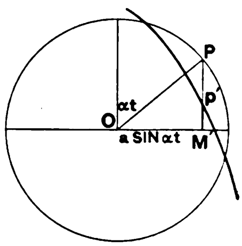

Fig. 5a.

the wave form figure. This length corresponds, of course, to tune $\frac{1}{a} \sin^{-1} \frac{OM}{a}$. The correct ordinate is as shown in my second figure (5*a*).

If Mr. Thomas is not clear about this he may find the analysis of the Lissajous figure $x=y=a \sin \omega t$ will help to make things plain.

E. C. ATKINSON.

Northwood, Middlesex.

Abstracts and References.

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PROPAGATION OF WAVES.

Die Ausbreitung der Elektromagnetischen Wellen (The propagation of electromagnetic waves).—A. Sacklowski. (*Elektrische Nachrichten-Technik*, 4, January, 1927, pp. 31-74.)

At a discussion on propagation phenomena by the scientific committee of the Heinrich Hertz Society, it was decided to compile a list of references to the literature of the subject, the task being undertaken by Dr. Sacklowski. In addition to this bibliography, it was also thought desirable to make a concise survey of the results of the more important papers, particularly those appearing in the less easily accessible foreign journals. This summary is given here, followed by the exhaustive bibliography of the subject containing 474 references.

The survey considers in successive sections: field strength measurements, including methods, results and inferences; the propagation of long and medium waves, with the drawing up of transmission formulæ; the propagation of short waves and fading phenomena, polarisation and directional reception; theories on wave propagation both without and with a conducting layer, and in the latter case, without and with taking account of the earth's magnetic field; and lastly, experiments for the direct proof of the conducting layer.

Ein Sendeverfahren für kurze Wellen (A method of transmitting for short waves).—N. von Korshenewsky. (*Zeit. f. techn. Physik*, 7, December, 1926, pp. 594-598.)

Lecture delivered at the 89th meeting of German scientists at Düsseldorf last September.

By short waves here is understood the whole range of wavelengths whose propagations from transmitter to receiver is effected essentially by means of normal reflection and refraction in the upper layers of the atmosphere. We know that the geometrical configuration of these layers and their electric and magnetic constants can differ very much and that they are subject to continual change. Now the intensity at the receiver depends not only on the direction of the radiation sent out, but also on the orientation of the p'ane of polarisation relatively to the position and condition of the refracting and reflecting surfaces in the atmosphere, and since these are continually changing, transmitting with waves linearly polarised always in one p'ane, as is usual in radio communication, cannot but be unsatisfactory, since an unfavourable orientation of the p'ane of polarisation relatively to the p'ane of incidence will produce extinction in the receiver. This follows from Fresnel's equations, also from the other laws of the electromagnetic theory of light which come into consideration for short wave transmission.

In order to avoid these diminutions in intensity (fading phenomena), the author recommends the employment of circularly polarised waves, since with these there is no preference for a certain direction of polarisation. To generate these waves two antennæ are used arranged at right angles to one another, excited with a phase difference of 90°, so that the field sent out is circularly polarised, *i.e.*, a rotatory field. A diagram of the circuit arrangement is shown below:—

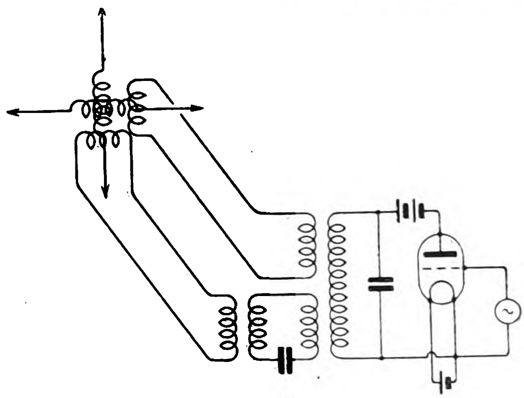


Fig. 2.

The employment of circularly polarised waves will also reduce variations in the intensity received that arise from alterations in direction of the p'ane of polarisation relatively to the direction of the receiving antenna.

A further cause of fading is interference between two or more rays that have travelled from transmitter to receiver by different paths, as represented in the figure below:—

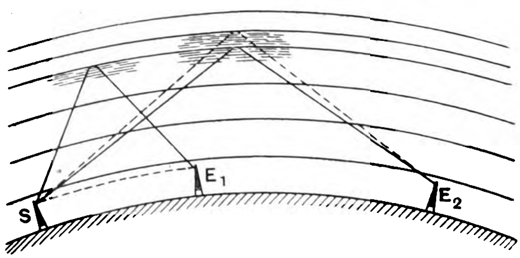


Fig. 3.

When the receiver is at E_1, a relatively short distance from the transmitter at S, interference can occur between direct and indirect rays, while when the receiver is at E_2 which is far enough away for the direct ray to have become quite absorbed, interference can take place between two rays reflected at different surfaces of separation.

Fading of this origin as well as that previously referred to can be eliminated by employing linearly polarised waves whose direction of polarisation is continually changing. In order to produce such waves a right-handed and a left-handed circularly polarised field are combined, the resulting field being linearly polarised with its p'ane of polarisation determined by the initial phases of the two rotatory fields. The oscillations of one

or both fields are interrupted in high frequency rhythm, so that the phase difference of the fields is continually changing, and thus a linearly polarised field is obtained with its direction of polarisation constantly varying. The technical solution consists in employing two ionised pairs of antennæ oscillating with a phase displacement of 90° or 270°, the oscillators being interrupted by means of a valve arrangement working at high frequency. The oscillators of wave trains produced in this way, with the relatively great differences of path that occur, are no longer coherent and consequently no longer able to interfere.

Über die Ausbreitung der Wellen in der drahtlosen Telegraphie (The propagation of waves in wireless telegraphy).—A. Sommerfeld. (*Annalen der Physik*, 81, 1926, pp. 1135-1153.)

In a work of this same title in volume 28 of these *Annalen* (pp. 665-736, 1909), the author dealt with the problem of the *vertical* antenna, with any kind of homogeneous ground, and a flat earth, and the antenna idealised as a simple Hertzian dipole for its effect at great distances. H. v. Hoerschelmann (*Jahrbuch d. drahtl. Tel.*, 5, pp. 14 and 188, 1912) then investigated the problem of the *horizontal* antenna, more exactly the Marconi bent antenna, the essential part of which is the horizontal arm. In this article the results of both papers are systematically summarised and simplified. Further, the author shows that the so-to-speak dual problem of a "magnetic antenna" of vertical or horizontal axis—*i.e.*, a frame with the windings in a horizontal or vertical plane—is capable of entirely corresponding treatment, the possibility of regarding frame antennæ as magnetic linear antennæ having been pointed out by Barkhausen. Of course, the frame antenna could also be represented by four electric dipoles in the plane of the frame displaced in phase, corresponding to the four sides of the frame, but this representation would be less simple mathematically and would not express clearly the analogy to the electric antenna. The mathematical treatment is divided into five parts, headed as follows :—

1. The electric and magnetic vertical antenna.
2. Discussion on surface waves and the formulæ for small numerical distance.
3. The electric and magnetic horizontal antenna.
4. Discussion on surface waves, the directional effect and its explanation by means of vertical earth currents.
5. The field of the electric and magnetic horizontal antenna.

Eine Ergänzung zur Theorie des rotationssymmetrischen Strahlungsfeldes (Supplement to the theory of the radiation field of rotational symmetry).—E. Spenke. (*Annalen der Physik*, 82, pp. 155-160.)

Kiebitz has deduced the differential equation for the direction of the electric field in the general case of the radiation field of rotational symmetry from Maxwell's field equations (*Ann. d. Phys.*, 80, p. 728, these abstracts *E.W. & W.E.*, January, 1927, p. 49). The differential equation for the case of the conducting sphere was strictly solved and it was found that the field direction could be represented by circles with their centres on the axis of symmetry, cutting the sphere at right angles. In the present investigation it is shown that the circular form of the field lines is not limited to the case of the conducting sphere, but holds quite good generally for all conductors of rotational symmetry. This is of importance for the application of the theory, since it enables the field lines to be constructed for every individual case and therefore also the paths of their perpendicular trajectories, the rays.

Radio Broadcast Coverage of City Areas (Abridged).—L. Espenschied. (*Journ. Amer. Inst. Elect. Engineers*, 46, January, 1927, pp. 25-32. *Bell System Technical Journal*, 6, January, 1927, pp. 117-141.)

An article dealing with the attenuation and fading which attend the spreading out of broadcast waves. A field strength contour map is shown of the measured distribution of waves broadcast by Station WEAF over the New York metropolitan area. A rough correlation is given between measured field strengths and the serviceability of the reception in yielding good quality reproduction. The range of a station as estimated in terms of year-round reliability is found to be relatively small. The question of the preferred location of a transmitting station with respect to a city area is considered. It is shown that an antenna located upon a tall building may radiate poorly at certain wavelengths and well at others. Surveys are presented of the distribution effected by an experimental transmitting station located in each of several suburban points. The locations are compared upon the basis of the "coverage" of receiving sets which they affect. The relation which exists regarding interference between a plurality of broadcast transmitting stations operating in the same service area is also considered. The importance of high selectivity in receiving sets is emphasised and measured selectivity characteristics for receivers having different types of circuits are shown.

Tests of Radio Propagation on Short Wavelengths.—M. Prescott. (*General Electric Review*, 30, February, 1927, pp. 113-116.)

A brief account of propagation tests recently conducted by the General Electric Company to determine the usefulness of short waves for spanning distances of one or two hundred miles. The wavelengths used were representative of those that have been allocated for point to point commercial work. The following conclusions are drawn with reference to these tests only, and without taking into account the two important factors of seasonal variation and the nature of the intervening country.

1. Channels comprising wavelengths shorter than those of the 66.3 to 75 metre channel will not give economical service at points within 100 miles of the transmitter.
2. The 66.3 to 75 metre channel, the 85.7 to 105 metre channel, and the 133 to 150-metre channel are capable of rendering economical service at points within 100 miles of the transmitter.

3. For daylight communication at distances not greater than 90 miles from the transmitter, the 133 to 150 metre channel will give better satisfaction than the 85.7 to 105 metre channel. Similarly the 85.7 metre channel will give better service than that which can be obtained under the same conditions using the 66.3 to 75-metre channel.

4. The above conditions are reversed when distances between 90 and 200 miles are considered. In this case, the 66.3 to 75-metre channel will give better service during daylight than the 85.7 to 105 or 133 to 150 metre channel.

FURTHER MEASUREMENTS ON WIRELESS WAVE-FRONTS.—R. Smith-Rose and R. Barfield. (*E.W. & W.E.*, 4, March, 1927, pp. 130-139.)

The authors explain how they obtained direct evidence of the existence of downcoming waves at the earth's surface, and were able to make fairly accurate measurements of the angle of incidence or elevation at which such waves arrive.

EFFECT OF A LARGE NUMBER OF RECEIVING AERIALS ON THE PROPAGATION OF WIRELESS WAVES.—R. Barfield. (*Nature*, 119, 5th February, 1927, p. 195.)

Evidence is given for the conclusion that the large number of receiving aerials in the London area have a very marked absorbing effect on the waves passing over them, an increase in intensity of the order of 90 per cent. having been observed at Slough, on transmissions from 2LO, for a variation of only 5 per cent. in the normal wavelength (to which the majority of the aerials may be considered tuned).

REFRACTION OF ELECTROMAGNETIC WAVES ROUND THE EARTH'S SURFACE.—J. McPetrie and R. Wilmotte. (*Nature*, 26th February, 1927, p. 317.)

The authors arrive at the result that the general condition under which a ray can return from the upper atmosphere is that the second differential of the dielectric constant with regard to height should be negative. It is also shown that, in the case of the earth's atmosphere, the density on the assumption made varies in such a manner that this differential is positive. The conclusion does not hold for rays at angles of elevation of less than 1° or 2°.

REPORT CONCERNING THE OBSERVATION OF THE INFLUENCE ON THE PROPAGATION OF RADIO WAVES, OF THE SUN ECLIPSE OF THE 14TH OF JANUARY, 1925, IN THE DUTCH EAST INDIES.—E. Holtzappel. (*Proc. Inst. Radio Engineers*, 15, January, 1927, pp. 61-62.)

AN ATTEMPT TO DETECT A CORPUSCULAR RADIATION OF COSMIC ORIGIN. — W. Swann. (*Journ. Franklin Institute*, 203, January, 1927, pp. 11-33.)

Experiments are described the results of which indicate that the absolute magnitude of the current absorbed by a solid copper cylinder 20.6 cm. in diameter and 19.3 cm. high is no more than 1.5 per cent. of that which would have been obtained by the complete absorption of a vertical corpuscular current of density sufficient to account for the replenishment of the earth's charge. Incidentally, moreover, such small effect as is found in these experiments represents a rate of acquirement of *positive* charge, and is thus of the wrong sign to participate in the replenishment of the earth's charge. This however is not thought to present us necessarily with an anomalous situation, since the charging may be brought about by the ejection of electrons from the air by the penetrating radiation, those ejected within striking distance of the earth entering it and charging it up until equilibrium is established with the atmospheric-electric conduction current.

ATMOSPHERICS.

OBSERVATIONS ON THE ATMOSPHERIC DISTURBANCES.—T. Nakagami and K. Kaneko. (*Journ. Inst. Elect. Engineers of Japan*, December, 1926, pp. 1423-1436.)

An account of the investigation of atmospherics at Osaka, with the apparatus and method employed, and giving the results obtained. The conclusions arrived at from the observations are as follows :—

1. Atmospheric disturbances increase when it is sunset at the receiving station, high values prevail during the night, decreasing fairly rapidly after sunrise.

2. The directions from which atmospherics are observed to come seems to warrant the conclusions that they originate in general over land rather than over the ocean.

3. In summer atmospherics come from the north-east and in winter from the south-west, showing that the sun has an important bearing upon the sources of atmospherics. These appear to the author to follow the sun in its changing path between the northern and southern hemispheres. Besides local disturbances from the mountain range known as the "Japanese Alps," there are also atmospherics from a distance. This fact is shown by the directional observations made at Iwatuki near Tokio where atmospherics were found to come from the north to the north-west.

4. Measurements made at Pekin during October and November, combined with the data obtained at Osaka, indicate that at this season atmospherics originate in the tropical region of the Dutch Indies.

UN ENREGISTREUR DE LA FRÉQUENCE DES ATMOSPHÉRIQUES ; SON UTILISATION EN MÉTÉOROLOGIE (A recorder of the frequency of atmospherics and its use in meteorology).—R. Bureau, A. Viant and A. Gret. (*Comptes Rendus*, 184, 17th January, 1927, pp. 157-158.)

Recording apparatus has been devised that traces a curve the ordinate of which is proportional to the frequency of atmospheric disturbances. A radio receiver attached to a relay picks up disturbances, the relay at each disturbance received sending a current through the electro-magnet of a Richard wind recorder, which traces a curve whose ordinate is proportional to the frequency of the electric contacts thus produced. An analysis of the curves obtained shows the closest connection between the variation of the frequency of atmospherics and the passing over of continuities which

cause them. Two conclusions are drawn from this relationship :—

1. A large number of atmospherics have their source in the physical properties of the air in the *immediate* neighbourhood of the receiver.

2. The recording of the frequency of atmospherics is one of the most potent means of analysing the detailed structure of meteorological discontinuities, in particular those of principal and secondary cold fronts.

SIMULTANEOUS ATMOSPHERIC DISTURBANCES IN RADIO TELEGRAPHY.—M. Bäumler. (*Proc. Inst. Radio Engineers*, 14, December, 1926, pp. 765-771.)

A translation of the paper in *Elek. Nachr. Technik.*, 3, 11, pp. 429-433, of which there was an abstract in *E.W. & W.E.*, February, 1927, p. 116.

PROGRESSIVE LIGHTNING.—C. Perrine. (*Nature*, 19th February, 1927, p. 278.)

In *Nature* of 20th November last, Prof. Boys refers to observations of "multiple flashes"—that is, flashes succeeding one another along the same path (these abstracts, *E.W. & W.E.*, January, 1927, p. 50).

The writer of the present letter states that while there is no doubt of the reality of these *appearances* of multiple flashes, he has very serious doubts of there being more than one flash in reality.

From the fact that the multiple flashes he has observed at Cordoba have always been at a great distance and never near by, he concludes that they are due in some way to erratic refraction in the atmosphere.

In reply, Prof. Boys writes that these observations are interesting as indicating a difference in the appearance of lightning in the Argentine, where the strokes are exceptionally strong, and in Great Britain. Here, without any question, the appearance of the multiple flash is found when the distance is very small indeed.

PROPERTIES OF CIRCUITS.

FORCED OSCILLATIONS IN A CIRCUIT WITH NON-LINEAR RESISTANCE (Reception with reactive triode.)—B. van der Pol, Jun. (*Philosophical Magazine*, 3, January, 1927, pp. 65-80.)

Seven years ago the problem of forced oscillations in a circuit with non-linear resistance was investigated for the first time by the author (*Tijdschr. v. h. Ned. Radiogen.*, 1, 1920, p. 1). The differential equation

$$\ddot{v} + \phi(v)\dot{v} + \omega_0^2 v = \omega_1^2 B \sin \omega_1 t$$

deduced at the time, again forms the basis of the present investigation. The remarks, however, were then confined solely to dealing with the case where the resistance remained positive. Three years later the general theoretical problem where the resistance could also be negative was investigated in collaboration with Dr. Appleton (*Proc. Cam. Phil. Soc.*, 23, 1923, p. 231). The present article is still more general and gives a more detailed account of the experiments.

A MODIFIED BEAT METHOD OF COMPARING TWO HIGH-FREQUENCY OSCILLATIONS.—(*E.W. & W.E.*, 4, March, 1927, p. 174.)

FURTHER NOTES ON SIMPLE RESONANCE CURVES.—E. Mallett. (*E.W. & W.E.*, 4, March, 1927, pp. 151-159.)

TRANSMISSION.

SIMULTANEOUS PRODUCTION OF A FUNDAMENTAL AND A HARMONIC IN A TUBE GENERATOR.—H. Walls. (*Proc. Inst. Radio Engineers*, 15, January, 1927, pp. 37-39.)

The published methods for transmitting and receiving two or more frequencies from a single antenna contemplate independent modulation of the several frequencies and require a separate generating valve for each frequency. The method described here involves only a single valve. The immediate application intended was the simultaneous transmission of several standard frequencies, the work being part of the standard frequency transmission programme of the Bureau of Standards, but other applications are pointed out.

ÜBER STEUERUNG MIT EISENDROSSELN (On modulation with iron chokes). — R. Strigel. (*Zeitschz. f. Hochfrequenz*, 29, January, 1927, pp. 10-20.)

Description of research carried out under the direction of Prof. Zenneck on oscillatory circuits which contain an iron choke with superimposed direct current. Investigation is made of :—

I. The tension appearing at the iron choke with the different circuits.

II. The inductance and loss resistance of the iron choke in relation to the superimposed direct current with the various arrangements.

III. The influence of tuning the circuit on the modulation characteristic.

The results are shown by means of oscillograms and plotted curves.

PIEZO-ELECTRIC CRYSTAL-CONTROLLED TRANSMITTERS.—A. Crossley. (*Proc. Inst. Radio Engineers*, 15, January, 1927, pp. 9-36.)

After describing the piezo-electric crystal and the history of its discovery and application, the author outlines the development of crystal-controlled valve oscillators by the Naval Research Laboratory of the United States. Various means of amplifying the output of a crystal-controlled oscillator are mentioned, a description being given of the best method, which consists of balancing or neutralising the various stages of amplification and also observing proper precautions for reducing grid-circuit losses by using high values of biasing voltage. A complete high-power low-frequency crystal-controlled transmitter is described and a schematic wiring diagram of circuits employed in this transmitter shown, also a diagram and illustrations are given of one type of low-power high-frequency transmitter.

A D.C.-A.C. CRYSTAL-CONTROLLED TRANSMITTER.—J. Clayton. (*Q.S.T.*, 11, February, 1927, pp. 31-33.)

DIE STRAHLUNG DER LUFTLEITERANLAGE AM HERZOGSTAND (The radiation of the aerial arrangement at Herzogstand).—M. Bäumler. (*Elekt. Nachr. Technik*, 3, December, 1926, pp. 467-473.)

An account of field strength measurements carried out at various places around the aerial.

DER WIDERSTAND DER LÜFTLEITERANLAGE AM HERZOGSTAND (The resistance of the aerial system at Herzogstand).—W. Fischer. (*Elekt. Nachr. Technik*, 3, December, 1926, pp. 462-466.)

In spite of the high resistances measured in the first stages of the antenna construction, it is here described how experimental tests have shown that by extending the antenna arrangement to at least five lines and leaving a corresponding distance between the terminal insulators of the antenna and the rocky sides of the summit, a final value of less than 2 ohms is anticipated for the overall resistance.

THE HORIZONTAL HERTZIAN AERIAL FOR TRANSMISSION.—M. Scroggie. (*E.W. & W.E.*, 4, March, 1927, pp. 143-147.)

WEITERE UNTERSUCHUNGEN MIT DEM ZWEIRÖHREN- UND VIELRÖHRENGENERATOR KURZER ELEKTRISCHER WELLEN (Further investigations with the two and multiple valve generator of short electric waves).—M. Grechowa. (*Zeitschr. f. Physik*, 38, pp. 621-634.)

Continuing previous work (*Zeitschr. f. Phys.*, 35, 1925, pp. 50 and 59), the author studies the dependence of the wavelength and intensity of the oscillations on the working conditions and arrangement of the external oscillating circuit, and shows the results graphically. Wavelengths down to 18 cm. were obtained. Experiments with valves numbering up to seven showed that the oscillation intensity increases more rapidly than the number of valves.

RECEPTION.

PROGRESS IN RADIO RECEIVING DURING 1926.—A. Goldsmith. (*General Electric Review*, 30, January, 1927, pp. 67-72.)

A survey of the development of broadcast reception in the United States during the past year. The most conspicuous alterations in radio conditions are stated to be the advent of the higher power broadcasting station and the increased congestion in the ether resulting from the haphazard selection of modified or new wave frequencies that has followed the Government's recent attitude that the present radio law is inadequate for the control of broadcasting wave frequency assignments. Another marked change during the last year or two is said to be a greatly increased musical discrimination on the part of the public, and a correspondingly increased demand for high quality acoustic reproduction as based on the amplifiers and loud-speakers used. This article describes some of the constructional and electrical features that have evolved to meet this demand.

A NEW RELAY FOR MORSE RECORDING. (*Wireless World*, 2nd March, 1927, p. 262.)

An account of a new relay, details of which were disclosed by Dr. Richter and Dr. Geffcken at the meeting of the Association of German Scientists at Düsseldorf last September. The relay, which utilises a well-known property of the Neon lamp, is remarkably sensitive for the reception of wireless signals.

THE TUCKER MICROPHONE FOR RECEPTION.—H. Watson. (*E.W. & W.E.*, 4, March, 1926, pp. 148-150.)

UN AMPLIFICATEUR H.F. À BIGRILLES À COMMANDE UNIQUE (A double-grid H.F. amplifier with a single control).—R. Barthélemy. (*Radio Revue*, February, 1927, pp. 291-294.)

Lecture given to the " Radio Club de France," 4th November, 1926.

THE PURPOSE AND DESIGN OF BROADCAST RECEIVERS. (*E.W. & W.E.*, 4, March, 1927, pp. 166-168.)

Informal discussion at I.E.E. Wireless Section.

ÉTUDE DES FILTRES POUR L'ALIMENTATION DES POSTES DE T.S.F. (Investigation of filters for supplying radio receivers from the mains). —R. Barthélemy. (*Q.S.T., Français et Radio Electricité Réunis*, 8, January, 1927, pp. 25-29.)

TRANSFORMERS FOR THE NEW A.C. VALVE (*Wireless World*, 9th February, 1927, pp. 177-178.)

TWO-RANGE RADIO-FREQUENCY TRANSFORMER. (*Wireless World*, 2nd March, 1927, p. 261.)

Description of a radio-frequency transformer of sound construction marketed by the British Radio Corporation at Weybridge.

NEUE BEOBACHTUNGEN AM SELBST-TÖNENDEN KRISTALL (New observations on the spontaneously oscillating crystal). — F. Seidl. (*Physik Zeitschr.*, 27, 15th December, 1926, pp. 816-819.)

Description of experiments with the zincite-steel combination. The same circuit arrangement was used that Lossew (*W.W.*, 22nd Oct., 1924, p. 93, and *Radio Electricité*, 25th July, 1924, p. 181) employed for the crystal as oscillation generator, the crystal and counter-electrode being joined up in parallel with an oscillatory circuit.

LES CRISTAUX EN T.S.F. (Crystals in radio).—J. Vivié. (*Q.S.T. Français et Radio Electricité Réunis*, 8, January, 1927, pp. 17-24.)

This first instalment concerns the elements of crystallography. Two succeeding parts will deal respectively with galena and theories of detection and with quartz employed as an oscillator.

DIRECTIONAL WIRELESS.

ÜBER DIE VOM SCHIFF HERVORGERUFENE FUNKFEHLWEISUNG UND IHRE BESEITIGUNG (Errors in wireless bearings caused by the ship and their elimination).—F. Fischer (*Zeits. f. techn. Physik*, 7, 10, 1926, pp. 490-492.)

A theory is given of the systematic error introduced into bearings due to the presence of the ship and methods of compensation are described. The analogy with the deviation theory of the magnetic compass is point d out. The influence of listing and the ship's inclination lengthwise is also examined.

PORTABLE RADIO DIRECTION FINDER FOR 90 TO 7,700 KILOCYCLES.—F. Dunmore. (*Bulletin* No. 536, United States Bureau of Standards.)

Description of the development of a portable direction finder with but two controls—balancing and tuning—operating over a wide frequency band. This wide range is made possible by a set of seven interchangeable plug-in direction-finder coils, each with a corresponding heterodyne generator coil and a cam for operating the auxiliary tuning condenser. Another automatic condenser is connected in parallel with the main tuning condenser and is operated by a second cam of a shaft of the balancing condenser. Its function is to compensate for the detuning effect produced at the higher frequencies when the balancing condenser is operated. A shielding aluminium box contains all the receiving apparatus, including batteries, with the exception of the direction-finder coil, which is supported on a bakelite shaft extending through the box and rotated by means of a hand wheel.

VALVES AND THERMIONICS.

THE K.L.1 VALVE.—(*Electrician*, 98, 4th February, 1927, p. 118.)

An account of this new design of valve with indirectly heated cathode, dispensing with the need of the L.T. accumulator, also effecting increased efficiency and amplification without distortion by the employment of a cylindrical cathode. The valve characteristics are given.

BEHAVIOUR OF ALKALI VAPOUR DETECTOR TUBES. —H. Brown and C. Knipp. (*Proc. Inst. Radio Engineers*, 15, January, 1927, pp. 49-55.)

Since the original investigation of certain alkali vapour valves, used as detectors, was completed (*Bulletin* 147, Eng. Exp. Sta., Univ. of Illinois), new and more sensitive types of valves have been developed and put on the market. Interest has centred around comparing the efficiency of these later valves with the supersensitive ones (potassium sodium alloy) previously produced. An account is given here of how the comparative tests were carried out and the results obtained. The efficiency of the alloy detector was found to be approached only by the new radiotron UX200—A. Some peculiar features of behaviour of the alkali valves are also described and represented graphically. It is stated that these valves have proved ideal for durability, true tone reproduction, and non-critical adjustment of plate and filament voltages.

ZUR THEORIE DES THERMIONENEFFEKTES II. (On the theory of the thermionic effect, II.)—N. v. Raschevsky. (*Zeitschr. f. Physik*, 39, pp. 159-171.)

STEUERUNGSVORGÄNGE DURCH "FELDZERFALL" UND KIPPSCHWINGUNGEN IN ELECKTRONENRÖHREN (Modulation phenomena through "field decay" and tilting oscillations in valves).—E. Friedländer. (*Zeits. f. Techn. Physik*, 7, 10, 1926, pp. 481-484.)

The tilting phenomena which occur in a valve with the appearance of secondary electrons, when there is ohmic connection between grid and anode, can be employed to produce periodic alterations of charge in an inductance or a condenser. Circuit arrangements are shown and the oscillation phenomena discussed.

UNTERSUCHUNGEN ÜBER DEN GLÜHELEKTRISCHEN ELEKTRONENAUSTRITT BEI ZUSTANDSÄNDERUNGEN DES KATHODENMATERIALS (Investigations on incandescent electric electron emission with alteration of state of the cathode material).—A. Goetz. (*Physik. Zeitschr.*, 27, 1st December, 1926, pp. 795-796.)

MEASUREMENTS AND STANDARDS.

FREQUENCY MEASUREMENTS WITH THE CATHODE RAY OSCILLOGRAPH.—F. Rasmussen. (*Journ. Amer. Inst. Elect. Engineers*, 46, January, 1927, pp. 3-12.)

The oscillograph frequency measurement circuit described differs from previous circuits in the use of by-pass condensers and plate leaks which permit the connection of the oscillograph to A.C. circuits having large D.C. components and which allow the use of biasing controls for shifting the position of patterns on the screen. Reference oscillators, chosen for their high stability, are used in conjunction with the frequency standards. The well-known properties of Lissajous figures are developed for cases in which only one term of their ratios may be determined from the oscillograph pattern. The calibration of oscillators is discussed in detail. Interpolation formulæ are derived for use in making interpolations on the reference oscillators. Several special circuits are described.

ÜBER PIEZO-ELEKTRISCHE KRISTALLE BEI HOCHFREQUENZ (On piezo-electric crystals at high-frequency).—A. Meissner. (*Zeits. f. Techn. Physik*, 7, December, 1926, pp. 585-592; *Zeitschr. f. Hochfrequenz*, 29, January, 1927, pp. 20-24.)

Lecture delivered at the 89th meeting of German scientists at Düsseldorf last September.

A method is given for recording the resonance curves of quartz, and a new method of wave control employing the helium tube, also the quartz crystal is considered as a generator of oscillations. With plates cut in the plane of the optic axis, dis symmetry and air currents were detected, investigation of which led to the construction of a small quartz motor and also to a structural model for the quartz crystal. The relations between the optical and mechanical directions of rotation were determined.

A brief account of the generation of air currents and the rotation of the crystal is to be found in the *Wireless World* of 16th February, 1927, p. 202.

MEASUREMENTS ON RADIO-FREQUENCY AMPLIFIERS. —R. Smith-Rose and H. Thomas. (*Wireless World*, 2nd, 9th, 16th and 23rd February, 1927.)

A series of articles on the measurement of amplifier performance, the first being a review of present methods, and the subsequent articles dealing respectively with voltage amplification, the input

impedance of an amplifier, and intermediate amplifiers for supersonic heterodyne receivers.

TELEPHONE TRANSMITTER MODULATION MEASURED AT THE RECEIVING STATION.—B. van der Pol and K. Posthumus. (*E.W.& W.E.*, 4, March, 1927, pp. 140-141.)

A short account of a method of modulation measurement used at Eindhoven, which differs somewhat from that described by Mr. L. B. Turner, under the same title, in the January number of *E.W.& W.E.*

AN AUTOMATIC FADING RECORDER.—T. Smith and G. Rodwin. (*Proc. Inst. Radio Engineers*, 15, January, 1927, pp. 41-47.)

A device for automatically recording signal intensities is described with the method employed to amplify the signal sufficiently to operate a commercial type of graphic meter. Sample fading records of various transmissions are shown.

MESSUNGEN AN MIKROPHONEN UND TELEPHONEN (Measurements on microphones and telephones).—C. Hartmann. (*Elekt. Nachr. Technik*, 3, December, 1926, pp. 458-461.)

Discussion of objective methods of comparison.

LE CALCUL DES SELFS (Calculation of inductances).—Y. Doucet. (*Q.S.T. Français et Radio Electricité Réunis*, January, 1927, pp. 32-33.)

Continuation of a mathematical discussion begun in the previous issue.

A SHIELDED BRIDGE FOR INDUCTIVE IMPEDANCE MEASUREMENTS AT SPEECH AND CARRIER FREQUENCIES.—W. Shackelton. (*Bell System Technical Journal*, 6, January, 1927, pp. 142-171.)

Description of a shielded alternating-current inductance bridge adapted to the measurement of inductive impedances at frequencies up to 50,000 cycles.

A.C. MEASURING INSTRUMENTS.—K. Edgcumbe and F. Ockenden. (*Electrician*, 98, 11th February, 1927, pp. 140-141; *Electrical Review*, 11th February, 1927, pp. 232-235.)

Abstract of a paper read before the Institution of Electrical Engineers on 3rd February.

DIE WAHRSCHEINLICHKEITSRECHNUNG IN DER FERNSPRECHTECHNIK. (Calculation of probability in telephone technique).—F. Lubberger. (*Zeits. f. Techn. Physik*, 8, 1, 1927, pp. 17-25.)

GENERAL PHYSICAL ARTICLES.

AN INVESTIGATION INTO THE NATURE AND OCCURRENCE OF THE AURORAL GREEN LINE λ 5577 Å.—J. McLennan, J. McLeod and W. McQuarrie. (*Proc. Royal Society*, 114A, February, 1927, pp. 1-22.)

Description of recent work resulting in the conclusion that this green line is due to oxygen and occurs with greatest intensity when the oxygen is at a pressure equivalent to 2 mm. of mercury, the intensity being also increased when the oxygen is mixed with one or other of the gases: helium, neon or argon.

PHOTOELECTRIC EMISSION AS A FUNCTION OF COMPOSITION IN SODIUM-POTASSIUM ALLOYS.—H. Ives and G. Stilwell. (*Physical Review*, 29, February, 1927, pp. 252-261.)

BEITRÄGE ZUR ERKLÄRUNG DER ERSCHEINUNGEN BEI DER KATHODENZERSTÄUBUNG. (Contributions to the elucidation of cathode sputtering phenomena).—T. Baum. (*Zeitschr. f. Physik*, 40, pp. 686-707.)

DIE REFLEXION HERTZSCHER WELLEN AN FERROMAGNETISCHEN DRAHTGITTERN. (The reflection of Hertzian waves at ferromagnetic wire gratings).—W. Arkadiew. (*Annalen der Physik*, 81, pp. 649-665.)

Owing to the impossibility of measuring the absorption of Hertzian waves when they are reflected from metal reflectors, the reflection at Hertzian gratings is investigated. The magnetic properties for rapid electrical oscillations can be calculated from the theory that is extended here for the case of the ferromagnetic wire grating. The permeability and conductivity worked out here from experiment coincide with the curves constructed from the theory of magnetic dispersion, the parametres necessary being taken from observations of the absorption of electric waves at magnetic wires.

DIE REFLEXION ELEKTROMAGNETISCHER WELLEN AN FERROMAGNETISCHEN OBERFLÄCHEN (The reflection of electromagnetic waves at ferromagnetic surfaces). — W. Arkadiew. (*Zeitschr. f. Physik*, 38, pp. 908-919.)

AN ANALYSIS OF THE ELECTROMAGNETIC FIELD INTO MOVING ELEMENTS.—S. Milner. (*Proc. Royal Society*, 114, A, February, 1927, pp. 23-46.)

SUR LA POSSIBILITÉ DE METTRE EN ACCORD LA THÉORIE ELECTROMAGNETIC AVEC LA NOUVELLE MÉCANIQUE ONDULATOIRE (On the possibility of reconciling the electromagnetic theory with the new undulatory mechanics).—L. de Broglie. (*Comptes Rendus*, 184, 10th January, 1927, pp. 81-82.)

LA STRUCTURE ATOMIQUE DE LA MATIÈRE ET DU RAYONNEMENT ET LA MÉCANIQUE ONDULATOIRE. (The atomic structure of matter and radiation and undulatory mechanics).—L. de Broglie. (*Comptes Rendus*, 184, 31st January, 1927, pp. 273-274.)

ELECTROMAGNETIC THEORY AND THE FOUNDATIONS OF ELECTRIC CIRCUIT THEORY.—J. Carson. (*Bell System Technical Journal*, 6, January, 1927, pp. 1-17.)

An example of the type of problem to which the analysis presented is applicable is the coil antenna. The fact that the current depends not only on the line integral of the impressed electric intensity, but also on its mode of distribution along the length of the coil, may possibly have practical significance in the design of coil antennæ and their calibration at very short wavelengths.

PEUT-ON DÉCELER DIRECTEMENT LE MOMENT MAGNÉTIQUE DE L'ELECTRON ? Is it possible to find the magnetic moment of the electron directly ?—L. Brillouin. (*Comptes Rendus*, 184, 10th January, 1927, pp. 82-84.)

Experimental conditions are outlined which, although difficult, it is thought are not impossible to realise.

A QUANTUM RELATION IN LARGE SCALE ELECTRIC WAVE PHENOMENA.—T. Eckersley. (*Nature*, 119, 12th February, 1927, p. 234.)

ÜBER DIE DÄMPFUNG VON KLEINEN HERTZSCHEN VIBRATOREN (On the damping of small Hertzian vibrators).—W. Arkadiew and A. Leontiewa. (*Zeitschr. f. Physik*, 38, pp. 706-715.)

The observation of interference with Hertzian waves, with very great path differences, shows that extremely weak damped harmonics exist in addition to the strong damped fundamental oscillations in a Hertzian vibrator.

ÜBER DIE NATUR DER DIELEKTRISCHEN VERLUSTE (On the nature of dielectric losses).—K. Sinjelnikoff and A. Walther. (*Zeitschr. f. Physik*, 40, pp. 786-803.)

A theory of dielectric losses is constructed from the results of experiments on insulators. The problem is treated mathematically, and it is shown that the theory not only explains the dependence upon frequency and temperature that is found experimentally, but also makes a calculation of the absolute values of the dielectric losses possible.

DISCUSSION ON THE MECHANISM OF BREAKDOWN OF DIELECTRICS.—Hoover. (*Journ. Amer. Inst. Elect. Engineers*, 46, January, 1927, pp. 70-74.)

Mr. Hoover's paper appeared in the September number of this Journal, pp. 824-831 (these abstracts, *E.W. & W.E.*, November, 1926, p. 703).

DYNAMICAL STUDY OF THE VOWEL SOUNDS.—II. —I. Crandall. (*Bell System Technical Journal*, 6, January, 1927, pp. 100-116.)

Analyses of the frequency spectra of vowels show almost invariably two principal resonance peaks, which fact is suggestive of a double resonator to produce them. The present paper is concerned with the mechanism of the double resonator system and a mathematical treatment thereof.

THE PERFORMANCE AND DESIGN OF THE SOUND RADIATOR CONSISTING OF THE ACOUSTIC TRANSFORMER AND THE HORN.—K. Kobayashi. (*Journ. Inst. Elect. Engineers of Japan*, December, 1926, pp. 1437-1444.)

OPTIMUM CONDITIONS FOR MUSIC IN ROOMS.— F. Watson. (*Physical Review*, 29, January, 1927, p. 220.)

Abstract of a paper presented at the Chicago meeting of the American Physical Society, November, 1926. Musicians prefer rooms for playing that are reverberant, while listeners are better pleased with deadened rooms. A series of experiments was conducted to adjust these apparently contradictory conditions. After investigating a number of rooms of widely different volumes that varied in reverberant qualities, a final experiment gave the solution. A room adjusted for "perfect" conditions was found unsatisfactory for both playing and listening, but on transferring the absorbing material from the end of the room occupied by the players to the end used for listening, the conditions were regarded as very acceptable both for playing and listening.

A CONTINUOUS INTEGRAPH.—V. Bush, F. Gage and H. Stewart. (*Journ. Franklin Institute*, 203, January, 1927, pp. 63-84.)

Description of a mathematical instrument which is a continuously recording integraph and multiplier. It will multiply together two curves, or will integrate the product and will plot the resulting function ; it will also solve certain types of integral equations directly, without the necessity of evaluating the terms of a series.

DISCUSSION OF A METHOD FOR MAXIMISATION IN CIRCUIT CALCULATIONS (ROBERTS).—O. Roos. (*Proc. Inst. Radio Engineers*, 15, January, 1927, pp. 57-59.)

Mr. Roberts' paper appeared in *Proc. Inst. Radio Engineers*, 14, October, 1926, pp. 689-693 ; of which there was an abstract in *E.W. & W.E.* of December, 1926, p. 770.

STATIONS : DESIGN AND OPERATION.

DIE FUNKSENDESTELLE STUTTGART-DEGERLOCH (The radio transmitting station Stuttgart-Degerloch). (*Elekt. Nachr. Technik*, 4, January, 1927, pp. 76-77.)

An account of the new German transmitting station erected by the Reichspost to replace the temporary structure near Feuerbach and increase the broadcasting range of the South German Company. The new station is situated about 1½ km. to the south of Degerloch, at a height of 445 m. above the sea level, with open country in almost every direction, so that the conditions are favourable for good transmission. The studio remains in the Charlottenplatz, being connected with the transmitter by an underground lead about 6 km. long. The two iron towers carrying the T-shaped aerial are each 100 m. high and 138 m. apart. The equipment comprises a valve transmitter with outside control and intermediate circuit, three modulating valves, one control valve and six oscillating valves. The control and oscillating valves each take 1.5kW and work with 4,000 volts anode tension. The station was officially opened on 28th November last.

GERMANY—POWER RATING.—(*Electrical Review*, 28th January, 1927, p. 141.)

In accordance with the agreement recently concluded at Geneva, the transmitting strength of

the following German stations will be reduced as shown below :—

	Wave-length.	Old kW figure.	New kW figure.
Koenigswusterhausen	1,300	10	8
Frankfurt (Main)	428.6	10	4
Hamburg ...	394.7	10	4
Leipzig	365.8	9	4
Münster	241.9	3	1.5

The Langenberg station, which was officially inaugurated on 15th January, will have 25kW, instead of 60 on the old basis.

POLAND. NEW SERVICES.—(*Electrical Review*, 11th February, 1927, p. 219.)

Direct wireless communication has been opened between Poland and Syria, the Lebanon, Transjordania, Palestine, Egypt, Eritrea, and Abyssinia, and *vice versa*. Regular exchanges have been arranged between the central wireless station at Warsaw and the Orient Radio Co.'s station at Beirut.

SPANISH HIGH-POWER STATION.—(*E.W. & W.E.*, 4, March, 1927, p. 142.)

Some particulars of the transmitting station at Prado del Rey, about five miles west of Madrid, and the receiving station at Morata, some sixteen miles south-east of Madrid, to which both stations are connected by overhead wires and controlled from a central office.

BROADCASTING STATION KODR.—E. Turle. (*Wireless World*, 2nd March, 1927, p. 259.)

An illustrated description of the Radioperedacha Station set up at Kiev, under licence of the Soviet Government, and constructed principally by amateurs.

CHINA—NEW STATIONS.—(*Electrical Review*, 11th February, 1927, p. 219.)

The contract for a 2kW station with a wavelength of 250 to 550 metres, for installation at Mukden, has been awarded to a French firm, and that for a 1kW station with a similar wavelength, in Harbin, to an American firm. These two broadcasting stations are expected to be in operation early this year. Receiving sets will be taxed and licensed according to type and size: the licence fee for crystal sets to be about $3 a year, valve sets $6 a year, and a tax of 10 per cent. imposed on imported sets in addition to the regular Customs duties.

AUSTRALIA. NEW STATION. — (*Electrical Review*, 21st January, 1927, p. 101.)

At present Melbourne has two "A" class broadcasting stations (3LO and 3AR) and one "B" class station (3UZ). The erection of another "B" class station is contemplated, which will receive no revenue from licence fees, but will rely solely on advertising for its income. Suitable programmes of music and other special features are being arranged with one minute's advertising between each item!

NEW ZEALAND. NEW STATIONS.—(*Electrical Review*, 11th February, 1927, p. 219.)

The installation of powerful broadcasting stations at Auckland and Christchurch has been completed by the Radio Broadcasting Co. of New Zealand, Ltd., a subsidised company organised to operate a chain of broadcasting stations throughout New Zealand on a uniform basis. The Auckland station is already in service and those at Christchurch, Wellington, and Dunedin are expected to be ready shortly. Practically all of the equipment used in this area is American.

MISCELLANEOUS.

FIFTY YEARS' PROGRESS IN ELECTRICAL COMMUNICATIONS.—M. Pupin. (*Journ. Amer. Inst. Elect. Engineers*, January and February, 1927, pp. 59 and 171 respectively.)

The Presidential Address, delivered 27th December, 1926, by Prof. M. I. Pupin, retiring President of American Association for the Advancement of Science.

Stress is laid on the important part played by Maxwell's electromagnetic theory in the development of telegraphic and telephonic science. It is stated that, since Faraday, every great advancement in the art of electrical communication has originated in the research laboratories of the universities, and not in the test-rooms or research laboratories of manufacturing companies. The lecturer also points out that the natural electrical disturbances taking place in electrical circuits, such as static disturbances, fading, earth currents in cables, etc., deserve close study, as they may enable us to find the secrets of the natural processes going on in the sun, the central power-station which supplies the moving power to all our activities.

SOME DEVELOPMENTS IN THE ELECTRICAL INDUSTRY DURING 1926.—J. Liston. (*General Electric Review*, 30, January, 1927, pp. 4 66.)

In the section on radio transmission, p. 34, some new types of transmitters are described, produced on a commercial scale for operation at high power and short wavelengths, also a dummy antenna capacitor for testing high-power radio transmitters, and a spray insulator for insulating the anodes of high-power water-cooled vacuum tubes from the supply of cooling water. Mention is also made of a new insulating material with low dielectric loss, "Mycalex," which has proved valuable in the construction of transmitters operating at high power and short wavelengths.

PAST AND PRESENT: A FEW NOTES.—(*E.W. & W.E.*, 4, March, 1927, pp. 160-166.)

Presidential address to the R.S.G.B., by Brig.-General Sir H. Holden, delivered at the Institute of Electrical Engineers, on 26th January, 1927.

RADIO AT SEA—RECORD SHORT-WAVE TRAFFIC.—(*Electrical Review*, 28th January, 1927, p. 140.)

The Cunard liner *Carinthia* has just achieved record-breaking commercial communication between

ship and shore. When off Cape Leeuwin, Australia, she worked with the New Brunswick station, New Jersey, a distance of nearly 12,500 miles. The transmitter has a wave range of from 25 to 50 metres and employs a specially-constructed 500-watt anode dissipation valve, capacity-reaction being employed to control the oscillations. The receiver consists of a simple single-valve circuit thoroughly screened, which can be coupled with the ship's low-frequency amplifier to intensify signal strength if necessary.

Two-way Communication with the Antarctic.—W. Brown. (*Nature*, 12th February, 1927, p. 238.)

Contact with the Norwegian whaler, *Sir James Clark Ross*, call sign AQE, by the south shore of the Ross Sea, 78° 30′ south latitude, was obtained by C. W. Goyder from the Mill Hill School station, 2SZ, on 30th January, the messages exchanged constituting the first two-way communication with the Antarctic.

Radio in the Whaling Industry.—(*Nature*, 12th February, 1927, p. 255.)

The use of radio telephony by fleets of whaling ships has made the whaling industry a much less strenuous one. Radio direction finders have also proved of great value, particularly as the magnetic compass is of little use in the Antarctic regions.

La Nouvelle Réglementation de la T.S.F. (New regulation of wireless telegraphy).—(*Radio-Revue*, February, 1927, pp. 302-307.)

Enumeration of the new radio laws in France, made last December, after the publication of which all stations will be subject to the control of " l'Administration des postes, télégraphes et téléphones et du Ministre du l'Intérieur."

Radio Photography and Television.—E. F. W. Alexanderson. (*General Electric Review*, 30, February, 1927, pp. 78-84.)

Radio photography is an accomplished fact and good reproductions are shown of photographs that have been broadcast. Transmission by continuous and interrupted waves is discussed, and the multi-shade process. The television problem is outlined, the solution of which is considered possible when higher speed and more brilliant receiving projectors have been developed.

A Tour round Savoy Hill.—A. West. (*Wireless World*, 9th February, 1927, pp. 154-158.)

The first article of a series dealing with problems of sound in relation to broadcasting studios. The articles in the three succeeding issues consider, respectively, the application of acoustic principles in the development of broadcasting studios, the production of echo effects by variable draping and by artificial methods, and studio equipment.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

Pluaj Mezuroj ĉe Senfadenaj Ond-Frontoj.—D-ro. R. L. Smith-Rose kaj S-ro. R. H. Barfield.

La artikolo traktas daŭrigon de laborado de la samaj aŭtoroj priskribita en ĉi tiu gazeto je Septembro 1925a. Oni jam evoluigis aparaton por mallongaj ondolongoj, ekz., brodkastaj, kaj mezuroj estas priskribitaj ĉe ondofrontoj, t.e., diversaj kliniĝoj de la elektraj kaj magnetaj kampoj. La mezuroj estis faritaj per kliniĝanta Hertza vergo por flanka kaj antaŭena kliniĝo de la elektra kampo, kaj per kliniĝbobena ricevilo por la magneta kampo. Oni donas rezultantajn kurvojn, kun tabeloj montrantaj variadon de la anguloj de incideco de malsuprenirantaj ondoj, k.t.p.

Kiel klarigo pri la rezultoj, oni sugestas, ke multoblaj reflektoj okazas el la supra tavolo. La pligrandaj anguloj de incideco observitaj respondas al unuoblaj reflektoj el la tavolo, kaj la malpligrandaj anguloj al reflektoj alterne ĉe la tavolo kaj ĉe la tera surfaco. La altecon de la tavolo on taksas je 90 kilometroj.

PROPRECOJ DE CIRKVITOJ.

Pluaj Notoj pri Simplaj Resonancaj Kurvoj.—Prof. E. Mallett.

La artikolo estas daŭrigo de tiu en la antaŭa numero. La nuna artikolo pritraktas la okazojn de du cirkvitoj kuplitaj aŭ magnete aŭ elektrostatike. Oni montras, ke kurvoj povas esti aŭ de la ordinara speco aŭ de la " zigzaga " speco. Diversaj aplikadoj de ĉi tiuj estas priskribitaj. La temo estas traktita laŭ la rubrikoj, (1) Unu cirkvito agordita, kuplita per komuna indukteco, aŭ la frekvenco aŭ la agorda kapacito estante variigita, (2) La sama kun kondensatora kuplo, (3) Du cirkvitoj agorditaj, kuplitaj per komuna indukteco, la kondensatoroj estante variigitaj, (4) Dinanometra efekto, kaj (5) Aplikadoj, t.e., determinoj de frekvenco, altfrekvenca rezisteco, indukta kapacito, k.t.p.

SENDADO.

La Horizontala Hertza Anteno por Sendado. —M. G. Scroggie.

La artikolo diskutas la plej taŭgan tipon de radiadaj sistemoj por utiligo je mallongaj ondoj, kaj sugestas simplan Hertzan oscilatoron. Oni scias, ke la polarizo de mallongaj ondoj ĉe la ricevilo estas malsama je tiu ĉe la sendilo, kaj la ricevado per horizontalaj Hertzaj vergoj estas jam priskribitaj.

Oni tial sugestas horizontalan Hertzan vergon, kiel sendan antenon, kun la ekscito aplikita ĉe ĝia mezo. Oni poste diskutas la utiligon de Lecher'aj fadenoj kiel proviziloj, bone ilustritaj per diagramoj de nodaj pintoj por diversaj rilatoj de linia longeco kaj ondolongo. Praktika formo de Hertza anteno estas montrita, kaj kelkaj ekzperimentaj rezultoj priskribitaj.

RICEVADO.

La Celo kaj Desegno de Brodkastaj Riceviloj.

Resumo de neformala diskutado ĉe la Senfadena Sekcio de la Institucio de Elektraj Inĝenieroj, Londono, je 2a Februaro, 1927a. La diskutadon malfermis C. F. Phillips, kaj daŭrigis S-roj. L. C. Pocock, P. W. Williams, P. K. Turner, kaj aliaj.

La Mikrofono " Tucker " por Ricevado.—Prof. H. E. Watson.

Post mallonga priskribo kaj diskutado pri la principoj de la mikrofono, oni sugestas ĝian utiligon kiel sentemegan kunigilon je ricevado. La mikrofono konsistas el varmigita fadeno en sonora ĉambro, kaj la artikolo priskribas ĝian utiligon kiel malaltfrekvencan tonselektilon. Tial, ke la pli kutima mikrofona frekvenco de 250 voltoj ne estis konsiderita taŭga, oni faris eksperimentojn per diversaj fadenoj por funkcii je 1.000 cikloj kune kun taŭga resonatoro. Priskriboj kaj ilustraĵoj estas donitaj pri diversaj resonatoroj uzitaj, kaj oni diras, ke konsiderinda pliboniĝo okazis ĉe la proporcio de signalo je atmosfera forteco. Oni ankaŭ priskribas eksperimentojn rilate plialtajn rapidecojn de funkciado kaj la utiligon de la mikrofono kiel tonselektilon por signala interfero. Oni povas apartigi du staciojn funkciantajn, ĉiu 200 metrojn aparte de l'alia, je 20,000 metroj, aŭ 0.02 metro aparte je 200 metroj.

Telefonsendila Modulado Mezurita ĉe la Riceva Stacio.—D-ro. B. van der Pol and K. Posthumus.

Rilate al artikolo pri la sama temo en ĉi tiu gazeto, Januaro 1927a, alia metodo de mezurado estas priskribita. La elmeto el altfrekvenca amplifikatoro estas rektifita per diodo kun kondensatoro kaj rezistanco kiel ĉe krada rektifado. La aŭdfrekvenca tensio trans la kondensatoro estas mezurita per dua diodo uzanta retrogliteblan metodon kaj retroigan komutatoron, tiel, ke la supra kaj malsupra limoj de la modulado estas aparte mezuritaj. La procenta modulado estas poste facile kalkulebla.

MEZUROJ KAJ NORMOJ.

Modifita Bat-Metodo por Kompari du Altfrekvencajn Oscilatorojn.

La metodo priskribita traktas la utiligon de tria aŭ helpa oscilatoro, uzita kiel aŭtodino kaj kunigita al la telefon-aŭskultiloj aŭ malaltfrekvenca amplifikatoro laŭokaze. Norma oscilatoro kaj la oscilatoro normigota estas ambaŭ kuplitaj al la aŭtodino, kiu estas alĝustigita por heterodini ĉi tiujn signalojn je oportuna frekvenco. Tiuj-ĉi donos aŭdeblajn tonojn, kiuj estos kunagordeblaj, ĝis la batoj malaperos, kiam la norma oscilatoro kaj la oscilatoro provata kunagordas. Praktikaj notoj pri la funkciado estas ankaŭ donitaj.

DIVERSAĴOJ.

Matematiko por Senfadenaj Amatoroj.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto traktas Seriojn, enhavante la signifon de serio, la sumon de serio, konvergecon kaj divergecon, provojn por konvergeco, kaj kelkajn gravajn seriojn, k.t.p.

La Estinteco kaj la Estanteco: Kelkaj Notoj.

Prezidanta parolado al la Radio-Societo de Granda Britujo de Brig.-Generalo Sir H. C. L. Holden, K.C.B., F.R.S., M.I.E.E., je 26a Januaro 1927a.

La parolanto revuis la fruan historion de la Societo kaj diskutis modernajn evoluiĝojn, aparte rilate al valvoj, mallongaj ondoj, frekvenca stabileco, telefoniloj, rektifikatoroj por provizo per la elektraj ĉeftuboj, normigado. La aktiveco de la Societo kune kun aliaj societoj estis ankaŭ pritraktita.

Resumoj kaj Aludoj.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato) kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

Hispana Altpotenca Stacio.—Prof. G. W. O. Howe.

Mallonga priskribo pri la nova Hispana Altpotenca Stacio ĉe Prado de Rey, apud Madrido. La ricevado okazas ĉe Morata, dum kaj senda kaj riceva stacioj estas funkciigataj el centra oficejo en Madrido. La sendilo liveras 150 Kilovatojn, kun ondolongoj de 13,870, 10,560, kaj 8,340 metroj.

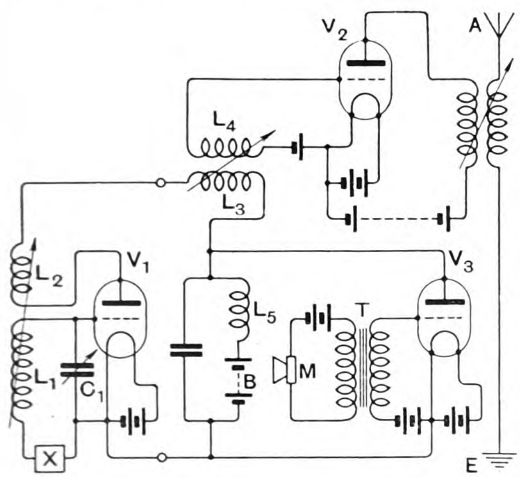
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

FREQUENCY BAND TRANSMISSION.

(*Convention date* (*U.S.A.*), *6th November*, 1924. *No.* 242,653.)

Some very interesting hypotheses to account for fading phenomena are given in the above British Patent, which gives details of a scheme for overcoming these defects. Marconi's Wireless Telegraph Company, Limited, and A. N. Goldsmith claim a method of short wave transmission in which

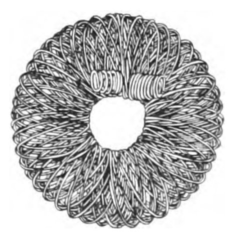


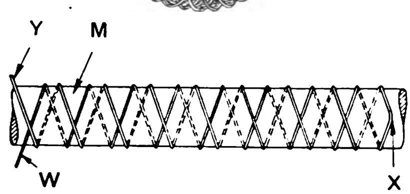
the frequency of the generated waves is periodically changed. Briefly, the specification points out that with short wave transmission there may be an earth wave and a reflected wave from the Heaviside layer. Simultaneous signal voltages occur from both paths at a receiving station, there being a phase difference between the two. This phase difference constantly varying owing to alteration in the Heaviside layer causes the magnitude of received potentials to vary correspondingly. However, if the frequency of the waves is altered there will be an alteration in the instantaneous values in the received potentials from the earth wave and the Heaviside layer reflected wave. The invention therefore consists in speech modulating a short wave, the frequency of which is continuously varied over small limits. The accompanying illustration shows one method of accomplishing this. The valve V_1 is provided with a grid inductance L_1, a capacity C_1, an anode inductance L_2, and the two are coupled together so as to produce continuous oscillations of very high frequency. The anode circuit also contains an inductance L_3 coupled to the grid inductance L_4 of a power amplifier valve V_2, which is coupled through the usual coils to an aerial system AE. A speech modulator valve is shown at V_3, and is provided with the usual microphone M and speech transformer T. The anode supply for the valves V_1 and V_3 is shown at B, and is connected through the usual choke L_5. The arrangement of the valves V_1 and V_3 is, of course, an ordinary choke control or constant current modulator system. Connected in the grid circuit of the generator V_1 is a device X which is used continuously to vary the frequency of the oscillations. The remainder of the circuit is quite straightforward, and will not be described in detail. The specification states that the frequency may be changed by a rotating condenser plate or mechanically adjusted variable inductance, but details are also given of a method of varying the constants of the grid circuit by the use of two oscillating valves which are caused to vary with the constants of the grid circuit of the valve V_1 by altering its inductance value.

A TOROIDAL COIL.

(*Convention date* (*U.S.A.*), *31st August*, 1925. *No.* 257,564.)

The Coto-Coil Company and E. F. Parks describe in the above British Patent the construction of a toroidal inductance suitable for high frequency circuits. The accompanying diagram should make the invention quite clear. M represents the





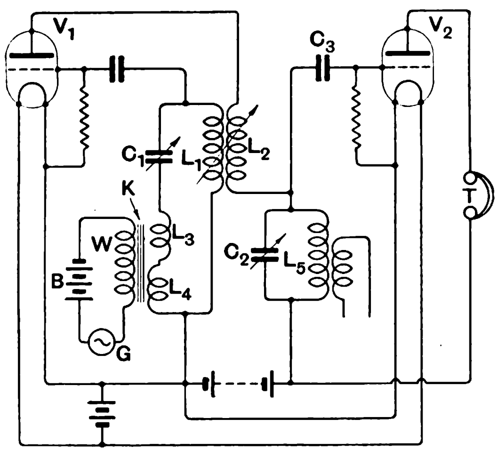
mandrel or axially rotated spindle of the winding machine on which the wire W is wound, the turns being spaced and wound with a definite pitch until they reach a point X, when the direction is reversed so that the wire returns at Y. Successive layers

may be wound if desired in this manner so that the coil is somewhat similar to the well-known honeycomb or duolateral type. The winding is then removed from the mandrel, and the completed coil is bent into a ring so that a toroidal coil results, having an appearance similar to that shown in the illustration.

ATMOSPHERIC ELIMINATION.

(*Convention date* (*France*), 15*th November*, 1924. *No.* 243,003.)

An atmospheric eliminating system is described in the above British Patent by L. Levy. The method employed consists in introducing some form of modulation which has the effect of modulating the amplitude of the desired signals and the frequency of the atmospheric signals. The atmospherics in this way produce very low frequency



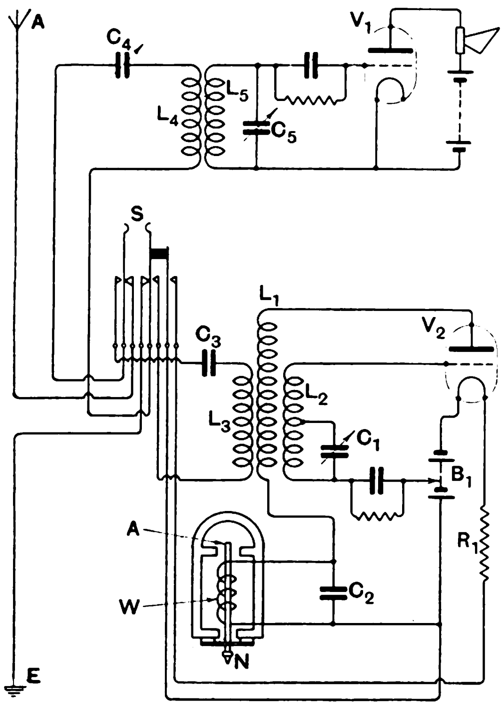
impulses which can be readily separated from the desired signals. The accompanying diagram shows one form of the apparatus. A valve V_1 is used as a first detector valve, the grid current containing an inductance L_1 and a capacity C_1, a reaction coil L_2 being coupled to the grid coil. In series with the tuned circuit L_1 C_1 are two inductances L_3 and L_4, which are wound over a core K, which is provided with a winding W in series with a battery B and an alternating supply or generator G. The two inductances L_3 and L_4 are wound in opposite directions. The direct current from the battery B produces in the core K a magnetic flux, the value of which can be so adjusted that any increase or decrease of the flux due to the alternating current from the generator G alters the permeability of the core. According to the variation of permeability there will be a variation in the inductance of the two coils L_3 and L_4. Since the inductance of these coils is changing, and, further, since they form part of the circuit connected to the grid of the valve, the natural frequency of the input circuit of the valve will vary. The anode circuit of this valve in addition to containing the reaction coil L_2, contains the tuned circuit L_5 C_2, which is coupled through a condenser C_3 to the input circuit of another detector valve V_2, the anode circuit of which contains the telephone receivers. The tuned circuit L_5 C_2 is tuned to double the frequency of the current supplied by the generator G. The input circuit of the first valve may be either directly or inductively coupled to an aerial system. Considering the effect of signal voltages upon the system, these will be detected in known manner and will give rise to audible signals in the telephones T. Since, however, the action of the special transformer and generator is to vary the constants of the input circuit of the valve V_1 it will mean that the effective voltage applied by the signal between the grid and filament of the first valve will vary, since it may be regarded as a circuit which is being periodically detuned. In other words, the amplitude of the received signals is modulated. In the case of an atmospheric, however, the effect is different. The effect of an atmospheric discharge is primarily to produce a voltage across the tuned input circuit by virtue of shock excitation, *i.e.*, oscillations are produced across the tuned circuit irrespective of the frequency to which it may be tuned. Each atmospheric discharge will cause in the circuit L_1 C_1 a series of wave trains, each modulated in frequency by the device W L_3 L_4, and slowly damped. If they are detected by the valve V_1 each damped wave train will cause the anode current of that valve to diminish. This diminution in anode current is periodic, and its frequency is very low. In fact it will be equal to the frequency of several wave trains caused by the atmospheric discharges, and is of the order of about fifteen or twenty per second. It states in the specification that it has been proved both theoretically and experimentally that impulses of this frequency upon the circuit L_2 C_5 do not produce any appreciable effect upon the detector valve containing the telephones, and in this way it is claimed that the effect of atmospherics is very materially reduced. The specification is extremely detailed, and contains a mathematical consideration of the various circuits, and also gives other modifications and arrangements.

ELECTRIC REPRODUCTION OF SOUND RECORDS.

(*Convention date* (*U.S.A.*), 2*nd June*, 1925. *No.* 253,096.)

Marconi's Wireless Telegraph Company, Limited, and J. Weinberger describe in the above British Patent Specification an arrangement which can be used for the reproduction of broadcast signals, or gramophone records by means of an electrical pick-up device. Dealing first with the pick-up arrangement, the normal gramophone sound box and needle are dispensed with, and are substituted by a needle or stylus N, which works on the face of the record, and communicates with a balanced electromagnetic system comprising an armature A pivoted about its centre point and working between a pair of poles at each end. A valve V_1 is arranged as an oscillator, and contains an anode inductance L_1 and a grid inductance L_2, a portion of which is tuned by a condenser C_1. The anode circuit of the valve contains the windings W of the magnetic system which are shunted by a

by-pass condenser C_2 to pass the high frequency currents occurring in the anode circuit of the generator valve V_1. A battery B_1 is used to supply both filament and anode voltages, the filament current being controlled by a resistance R_1. Movement of the needle N will be transferred to the pivoted armature which works in a strong

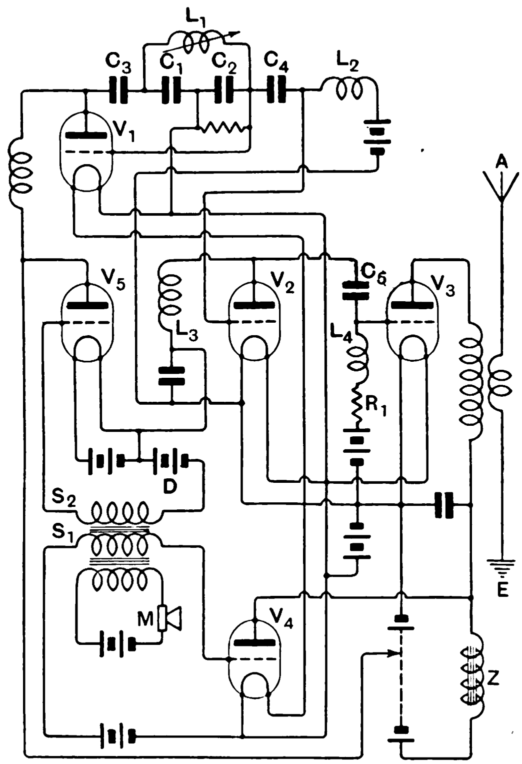


magnetic field. This will cause a change in flux which will produce potentials across the windings W. Since these are in the anode circuit of the valve they will vary the anode potential, and, therefore, modulate the high frequency current existing in the system. The output from this oscillator is transferred through an inductance L_3 and a capacity C_3 to another circuit L_4 C_4, which is coupled to a tuned circuit L_5 C_5, connected to the input of a detector valve V_2. When the valve V_1 is oscillating the high frequency current will be transferred through the circuit L_3 C_3 to the circuit L_4 C_4, and, in turn, to the circuit L_5 C_5, where it will be rectified. The detector valve contains the telephone receivers. Under normal conditions nothing will be heard in the telephones. When, however, the stylus is set into vibration by the sound trace of the record the potentials set up in the windings will modulate the high frequency current, and the modulated output will be detected by the valve, thereby energising the telephones or loud-speaker. The system may also be used for ordinary broadcast reception, in which case an aerial and earth system AE is included, and a master switch S is used to connect either the oscillator valve or the aerial system to the detector valve V_2.

A TRANSMISSION SYSTEM.

(*Convention date* (*U.S.A.*), 11*th May*, 1925. *No.* 252,027.)

A transmission system suitable for quiescent work, particularly useful for duplex telephony, is described in the above British Patent by the British Thomson-Houston Company, Limited, and I. F. Byrnes. The telephony system illustrated is one in which the main valves connected to the aerial system only radiate to any appreciable extent so long as there are any microphone potentials. How this is accomplished can be readily understood by examining the accompanying diagram, which shows a schematic arrangement of the system. The high frequency arrangement comprises a main amplifier, a sub-amplifier, and a drive. The drive or master amplifier valve V_1 is provided with a tuned circuit L_1 C_1 C_2, one end being connected to the grid and the other to the anode through another condenser C_3, the centre point of the condensers C_1 and C_2 being connected to the filament. The output of the oscillator is coupled to the first amplifier V_2 through a condenser C_4 and grid choke L_2. The anode circuit



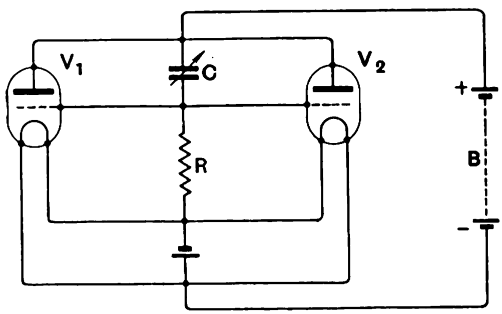
of the amplifier valve V_2 contains an inductance L_3 and is coupled through a capacity $C5$ to the grid of the main amplifier V_3, which contains a grid choke and resistance L_4 R_1. The anode circuit of the amplifier valve V_3 is coupled in the usual manner to the aerial system AE. The

microphone M is connected to the primary winding of a microphone transformer provided with two secondaries S_1 and S_2. The secondary S_1 is connected to the grid and filament of the modulator valve V_4, the anode of which is connected through a modulation choke Z to the source of anode supply B. The other secondary S_2 is connected between the grid and filament of another valve V_5, the grid of which is negatively biased with respect to the filament by means of a battery D. The valve V_5 is in series with the anode supply to the valve V_2, *i.e.*, the first amplifier. Obviously, if the grid of this valve is made sufficiently negative the impedance will be so high that practically no voltage will be applied to the anode of the valve V_2. As soon as voltages are impressed on the grid of the valve V_5 these voltages will overcome the negative voltage of the battery D and the impedance of the valve V_5 will be lowered, thereby permitting an appreciable current to flow to the anode circuit of the valve V_2. At the same time, however, the amplified high frequency oscillations from the valve V_2 will be impressed upon the valve V_3, thus rendering the aerial operative, but they will be modulated by the valve V_5, which is deriving audio-frequency potentials from the secondary S_1 of the microphone transformer. In this way there is only appreciable radiation from the aerial system when the microphone is actually being used, and a convenient duplex system can, therefore, readily be obtained.

A SHORT WAVE OSCILLATOR.

(*Convention date* (*Germany*), 10*th November. No.* 261,350.)

An interesting form of short wave oscillator is described in the above British Patent by Dr. A. Esau. The invention, which is illustrated in the accompanying diagram, consists in utilising a pair of valves connected in the manner indicated. The

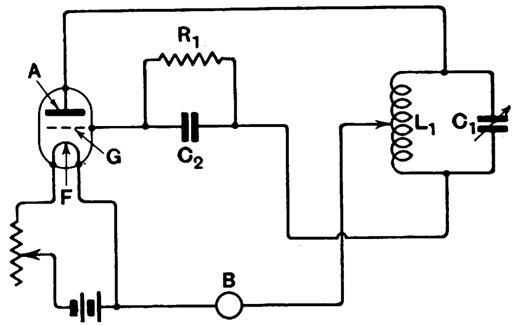


two valves V_1 and V_2 have their anodes connected together and connected to the filament through a source of positive potential B. The two grids are also joined together and connected to the filament through a resistance R. The specification states that the waves can be still further shortened by connecting a variable condenser C between the two anodes and the two grids. The specification also states that two similar oscillatory circuits are provided each constituted by the inter-electrode capacity of one valve, *i.e.*, the grid-anode capacity, the variable capacity C and the leads connecting the anode and grid to the condenser C. An aerial system may be either directly or inductively coupled to the system.

AN INTERESTING VALVE GENERATOR.

(*Convention date* (*Germany*), 11*th September*, 1925. *No.* 258,257.)

A very interesting form of valve generator is described in the above British Patent by Telefunken Gesellschaft für Drahtlose Telegraphie. The generator is of the type in which the grid is given a



permanent positive potential. The accompanying diagram shows the method in which the circuit is arranged. Here the oscillatory circuit comprises an inductance L_1 tuned by a capacity C_1. One end of the oscillatory circuit is connected to the anode A, while the other end is connected to the grid G through condenser C_2 shunted by a resistance R_1. A tapping on the inductance L_1 is connected to a source of positive potential B, the negative end of which is connected to the filament F of the valve. In this manner it will be seen that the anode and grid are both given a positive potential. Since the grid is positive there will be grid current flowing in the grid circuit, and this will cause a fall of potential along the resistance R_1, thereby maintaining the grid at a lower positive potential than that of the anode. It is stated that this circuit is conducive to the production of more gentle oscillations, and also does not give rise to the generation of undesired oscillations. The circuit is also claimed to be particularly efficient when the anode potential is derived from a source of alternating current.

EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. MAY, 1927. No. 44.

Editorial.

The Short-wave Echo Effect.

VIRTUE carried to excess may become a vice. This has happened with short-wave transmission, the principal virtue of which was the small attenuation with which the waves could travel to very great distances, even to the Antipodes, thus enabling schoolboys with a few watts to accomplish at times that which the wireless companies had failed to do with hundreds of kilowatts under the old dispensation. But, unfortunately, these short waves do not die out on arrival at the Antipodes but continue their journey around the globe with strength enough in some cases to cause serious interference with the waves which have taken the shorter path. This phenomenon was discussed by E. Quäck in the December number of the *Zeitschrift für Hochfrequenztechnik*, and was mentioned by T. L. Eckersley in a recent paper before the Wireless Section of the Institution of Electrical Engineers.

In October last the Radio Corporation of America began to transmit to Berlin from 2XT on 16.175 metres with an aerial input of 12 kilowatts. In full daylight a speed of 80 words per minute was reached, but the signals as recorded on the tape were often mutilated in a way that suggested that the waves which had travelled in the other direction around the globe were arriving a little after those which had taken the shorter path and interfering with the signals. At times the interference made working impossible. Fig. 1 is reproduced from a sample of tape given by Quäck. It shows how the letters *a b c* (-— —- - - - —- - —-) are mutilated. To investigate the phenomenon more fully, the engineers of the Telefunken Company received the signals on an oscillograph and the American station sent simply five dots per second. Fig. 2 shows the result; the middle curve is produced by a 50 cycle alternator and gives the time scale; the

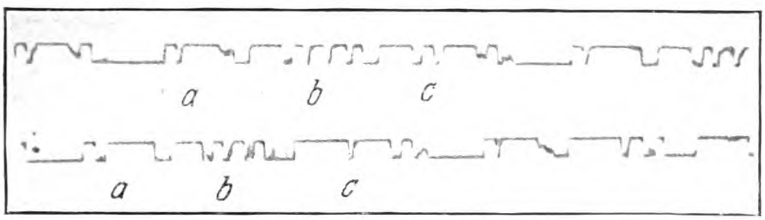


Fig. 1.

upper and lower curves show the same signal as received on two different aerials: the oscillograph has three loops. The main signal is marked *a* and the echo signal *a′*; one of the aerials was a dipol or Hertz aerial so inclined with reference to the polarisation of the waves that it showed no sign of the echo signal; on the other aerial the echo signal has about half the amplitude of the direct signal and arrives about 0.096 second later. At a speed of 299,800 kilometres per second this corresponds to a difference of path of 28,382 kilometres. To obtain greater accuracy the test was repeated, using an alternating current of 1,880 cycles per second to give the time scale. The result is shown in Fig. 3; this gave the time as 0.0957 second and the difference of path as 28,705 kilometres.

The difference between the signals received on the two aerials in this test is not always observed; sometimes both aerials receive the echo signal equally well.

A still more striking experiment consisted in transmitting from Nauen on a wavelength of 15 metres and a power of 8 kilowatts and receiving the signals at Geltow, both stations being near Berlin. The oscillograph of the received signal is shown in Fig. 4, *a* being the signal received directly over a distance of a few kilometres and *a′* that due to the waves which have encircled the globe. The time lag corresponds to a distance of 41,200 kilometres, which is more than the great-circle circumference of the earth, but is the length of path which the waves would have if they travelled at a height of 182 kilometres.

This echo phenomenon has only been observed with wavelengths between 15 and 22 metres but, as Herr Quäck points out, this range may be extended by the use of more sensitive receiving apparatus.

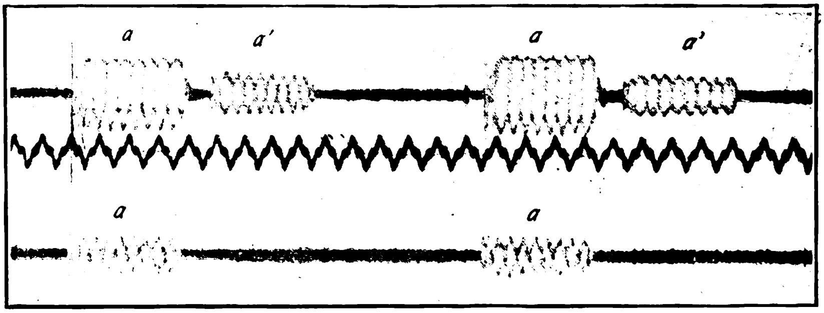


Fig. 2.

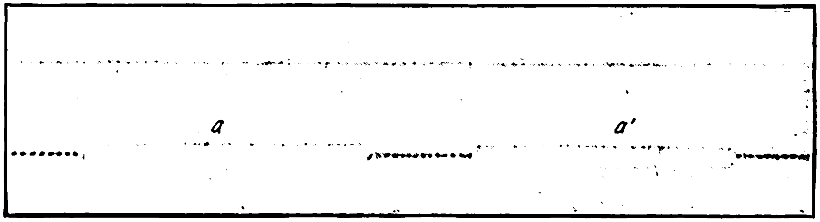


Fig. 3.

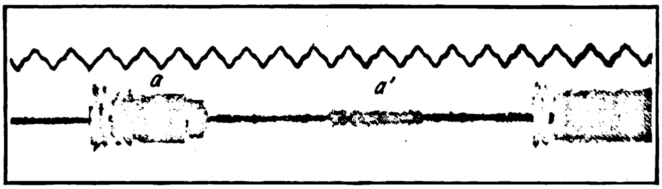


Fig. 4.

Phase and Group Velocities in an Ionised Medium.

By Prof. G. W. O. Howe, D.Sc.

IN the interesting experiments made in Berlin* to determine the time taken by a short-wave signal to encircle the globe, the length of path, and thus the height of the path above the earth, was deduced by multiplying the time interval by the velocity of light. To obtain an accurate value of the height, two things must be known to a very high degree of accuracy, viz., the time interval and the velocity of the wave, assuming, of course, that the ray follows a great circle at a fixed height. The need for great accuracy is due to the fact that the height is deduced from the difference between two very large distances, viz., the length of the path of the ray and the circumference of the earth. The results already obtained show that there is no insuperable difficulty in measuring the time interval to a high degree of accuracy, and, since the value obtained for the height of the ray is much greater than that hitherto considered probable, one is justified in wondering if the velocity of the wave may be appreciably less than that assumed. At first sight such an assumption appears to be quite contrary to the generally accepted theory that the waves are only able to encircle the globe because they travel in an ionised atmosphere in which their velocity is *greater* than that in free space. This contradiction is only apparent, however, as will be seen from the following considerations. When a train of waves, as shown in the figure, travels through an ionised medium, there are two different ways in which we can define the velocity. We can regard the group of waves as a whole, without considering the individual waves of which it is composed; if then the figure represents the positions of the group or train of waves at two successive moments of time, the distance travelled during the interval is D_g, and this distance divided by the time gives the group velocity. On the other hand, we may fix our attention upon any given crest, say that marked ×, and trace its progress. As the wave moves forward through the ionised medium, the vanguard *abc* is robbed of its energy in setting the electrons into oscillation, and this energy, less what is dissipated by electronic collisions, tends to maintain the waves as they die away. There is thus a continual eating away of the head and building up of the tail of the group of waves, with the result that our marked crest × gradually moves towards the head of the group. The distance D_p through which the marked crest has travelled during the interval divided by the time gives what is called the phase velocity. Now the phase velocity v_p is obviously greater than the group velocity v_g, and it can be shown that, whereas v_p is greater than the velocity c of light in a vacuum, v_g is smaller than c.

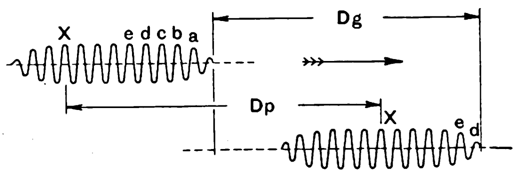


Fig. 1.

Now the curvature of the ray depends on the phase velocity v_p, and the short-wave ray is bent round and made to follow the curvature of the earth because this velocity is greater than c. The measurements made in Berlin determined the time taken for the group of waves to encircle the globe; and since this will depend on the time of arrival of the group of waves constituting the signal, irrespective of the individual waves, it will depend on v_g, which, as we have already said, is less than c.

It can be shown that

$$v_g = c\sqrt{(1-a)}$$

and $$v_p = c/\sqrt{(1-a)}$$

where $$a = \frac{N}{f^2} \cdot \frac{e^2 c^2}{\pi m}.$$

N = number of electrons in one cubic centimetre.

e = charge per electron = 1.591×10^{-20} electromagnetic units.

* E. Quäck, *Zeitschrift für Hochfrequenztechnick*, December, 1926, p. 177.

m = mass of electron = 0.9×10^{-27} grammes.

f = frequency = 15×10^6 for a 20-metre wave.

$$e^2 c^2/\pi m = 8.055 \times 10^7$$

and for $\lambda = 20$ metres.

$$a = N \times 3.57 \times 10^{-7}$$

Now for the group velocity v_g to differ by 1 per cent. from the velocity of light, it would be necessary for a to equal 0.02, whilst for v_g to differ by 5 per cent. a would have to be about 0.1. The above expression for a shows that

if $a = 0.02$; $N = 56{,}000$
if $a = 0.1$; $N = 280{,}000$

These are quite reasonable values of N. Appleton and Barnett deduced for certain conditions a minimum value of N of 100,000, and Appleton has recently (*Electrician*, 11th March) deduced a minimum value of 2.5×10^6. These are sufficient to show that the group velocity of the 20-metre wave may be several per cent. less than the velocity of light in a vacuum.

From the experimental results, Quäck calculated that the wave must have travelled at a height of 182 kms. If, however, we assume a velocity less than 299,800 kms. per second,, this height will be reduced. With a velocity 1 per cent. less than that assumed, the height would be reduced to 116.5 kms. and with a velocity 2 per cent. less the height would only be 51 kms.

It would appear, therefore, that the result of the experiment is not to determine the height at which the ray travels, but rather to determine from the assumed height the value of N the electron density in the medium through which the ray travels. Nothing very definite can be said on this point at present, because Herr Quäck expressly states that his results make no claim to great accuracy. Assuming the correctness of his figure of 182 kms. for the height of path based on a velocity of 299,800 kms. per second, we have the following results :—

If v_g =	0.99c	0.98c.
a =	0.02	0.04
N =	56,000	112,000
true height =	116.5 kms.	51 kms.

In a note in the *Wireless World* of 23rd March by a Berlin correspondent, it is stated that the height calculated from the German experiments is 350 kms. and not 182 kms. as given by Herr Quäck. If we adopt this figure we obtain the following results :—

If v_g =	0.98c.	0.97	0.96	0.95
a =	0.04	0.06	0.08	0.10
N =	112,000	168,000	224,000	280,000
true height =	216 kms	148 kms	81 kms	14 kms

It will be seen that N varies but little under these various assumptions ; an accurate determination of the time taken to encircle the globe would decide within narrow limits the electron density of the medium through which the ray travels.

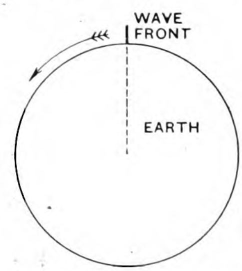


Fig. 2.

It is interesting to note that if the wave-front be assumed to travel around the earth, while the front itself remains radial as shown in the figure, so that the phase-velocity is proportional to the distance from the centre of the earth, then the group velocity must be inversely proportional to the distance to the centre, since $v_p \times v_g = c^2$. If now we assume that at the surface of the earth the velocity is the same as that in a vacuum, we can determine at what height the group velocity corresponds to the observed time interval. If we assume that the time interval gives a height of 182 kms. on Herr Quäck's calculation, it can be shown that the real height is about 90 kms., since at this height we are 1.0141 times further from the centre of the earth than we are on the surface. Hence $v_r = 1.0141\ c$ and $v_g = c/1.0141$; this reduction in the group velocity is just sufficient to reduce the calculated height from 182 to 90 kms. This would correspond to an electron density of about 80,000.

The Alignment Method in Linear Valve Characteristic Fields.

By W. A. Barclay, M.A.

BY the "linear field" of a valve characteristic, the writer intends that portion of the characteristic surface for which the individual characteristic curves are sensibly linear. It is within the linear field of the characteristic that it is desirable to confine the working point for the distortionless amplification of sinusoidal E.M.F.s. In what follows we shall confine ourselves entirely to a discussion of this linear field, and shall not be concerned with the curved portions of the characteristics and the problems to which they give rise.

It will be appropriate here to recall that the curves known as valve characteristics summarise in a convenient graphical form the statistical relations between various elements in the valve under usual working conditions. For the anode circuit of a valve the most important of these are: (1) The anode potential v_a, (2) the grid potential v_g, (3) the anode current i_a, and (4) the filament current i_f, upon which depends the filament temperature. For any given valve these four variables are inter-related, and the usual valve characteristic graphs show the relation between the first three only, the filament temperature being assumed to remain constant. We shall also avoid in the sequel all reference to the grid circuit of the valve, and neglect the reactions of any grid current upon the source of E.M.F.s. This assumption is quite justified for the negative values of v_g usually employed for voltage amplification.

With this proviso, and excluding the filament temperature from consideration, there are three possible graphical methods by which the relation between v_g, v_a and i_a may be shown, according to the three possible ways of selecting the co-ordinate axes. If OX and OY be taken to represent v_g and i_a respectively, the characteristic curves will represent values of v_a. This is the most usual type of valve characteristic whose uses are doubtless familiar to every reader. When OX and OY represent v_a and i_a, the individual curves represent values of v_g. This type of characteristic is used when it is desired to illustrate the effect of various kinds of load in the anode circuit, and has been dealt with recently in these pages. It may be mentioned that the slope of this characteristic gives a measure of R_0, the A.C. anode resistance of the valve at the working point. We have, when v_g is constant, $\partial v_a/\partial i_a = R_0$, so that the gradient of the curve is proportional to $1/R_0$. The third type, in which v_a and v_g are taken as axes while individual curves represent values of i_a, is only occasionally used.* In this type the slope of the "straight" portion gives an approximation to the amplification ratio μ_0 of the valve, *i.e.*, $\partial v_a/\partial v_g = \mu_0$.

It should be noted that each of the three graphical methods conveys the same essential information (which might equally well be set out in tabular numerical form). The differences between them lie only in the mode of presentation. In each, a portion of the graph is appropriated to the linear field, within which all the curves are approximately straight and sensibly parallel. It is in virtue of this fact that we may write the following equation, which holds only within the linear field:—

$$i_a = \frac{v_a + \mu_0 v_g - v_0}{R_0} \qquad \text{.. (1)}$$

This equation, in which μ_0, v_0 and R_0 are constants, expresses the linear relationship between v_a, v_g and i_a. The linear field of each of the above three graphical types of characteristic may thus be represented by this equation when the axes of co-ordinates are appropriately chosen.

A brief word may be given to the three constants of this equation. R_0 is, of course, the anode A.C. resistance of the valve, or, as it has been termed, the differential resistance $\partial v_a/\partial i_a$. For the purpose of facilitating the exposition, this resistance is assumed constant

* An example of this kind of characteristic occurs in Professor Fortescue's paper on "Sources of Distortion in the Amplifier," reported in the *Wireless World* of 16th January, 1924.

throughout the linear field, while μ_0, the amplification factor of the valve, is likewise assumed to be constant. The actual voltage magnification obtained by inserting a load in the anode circuit is denoted by μ. When this load is a pure resistance R, μ is always less than μ_0. We have, in fact,

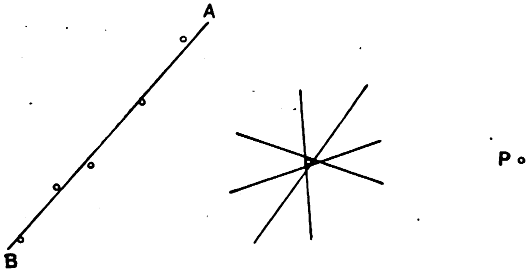
$$\mu=\mu_0 . \frac{R}{R+R_0}$$

The constant v_0 of equation (1) is not so well known as the other two. It represents the back E.M.F. due to the electronic current within the valve, *i.e.*, it measures the diminution of plate voltage caused by this current. Like the others, v_0 also is constant throughout the linear field. It has been termed the "space charge effect." *

The true nature of equation (1) is often lost sight of. It is important to remember that it is essentially an experimental equation, the constants of which must be determined by experiment for each individual valve. Naturally, these constants should be the best available from the observational data: in other words, the equation of the linear field should be the linear equation which most nearly represents the data within the limits of the field. Obviously it can never quite succeed in doing so, because the individual measurements are each affected by possible errors of observation, while in addition we know that the characteristic curves themselves are never strictly linear, however closely they may approximate to this form over a wide field.

In undertaking to find the constants μ_0, v_0 and R_0 for the linear field of any valve, the problem before us is, if we tackle it graphically (as is usually done), that of drawing the straight lines which most nearly pass through certain given points on the graph. The precise position and slope of these lines is by no means easy to determine with confidence, and mathematical methods depending upon the Theory of Errors and Least Squares may be rejected as altogether too recondite for the needs of the problem. Within recent years, however, the advent of the Alignment Principle has provided the experimenter with yet another tool in the correlation of his observations, a tool at once easy of application and efficacious in its results. The particular method described below, which is one of several elaborated by the writer for the representation of valve linear characteristics, will, it is confidently believed, be found to possess many important advantages over the graphical procedure. These may be briefly enumerated.

In the first place, the problem of drawing the best straight line among several approximately collinear points is replaced by the undoubtedly easier task of finding the position of the point which will best represent the intersection of several approximately concurrent straight lines. (See Figs. 1a and 1b.) A second great advantage of the Alignment Diagram is that upon it *all* values of *each* variable may be represented, instead of only a limited number in the case of *one*,



(a) (b)

Fig. 1a. *These points may be represented by the line* A B.

Fig. 1b. *The intersection of these lines may be represented by a single point* P. (*The lines may be erased.*)

due to the inconvenience of multiplying unduly the number of lines upon the graph. A third feature is the exceedingly comprehensive nature of the diagram, which shows at sight the simultaneous variations of many more factors than can be made to appear conveniently upon the graph. Instead of having, as was shown above, one graph suitable for the estimation of μ_0, another for R_0, and so on, we have now one diagram upon which not only the variations of v_a, v_g and i_a can be read, but also those of the quantities v_0, R_0, R, μ_0 and μ. Moreover, no special construction need be drawn on the diagram to obtain these. The fourth and greatest advantage secured by the use of the new method is that the linear field characteristics of any number of valves may be drawn upon the same chart. The amplifying performance

* See "The Algebra of Ionic Valves," by Dr. Eccles in the *Electrician*, 13th February, 1920.

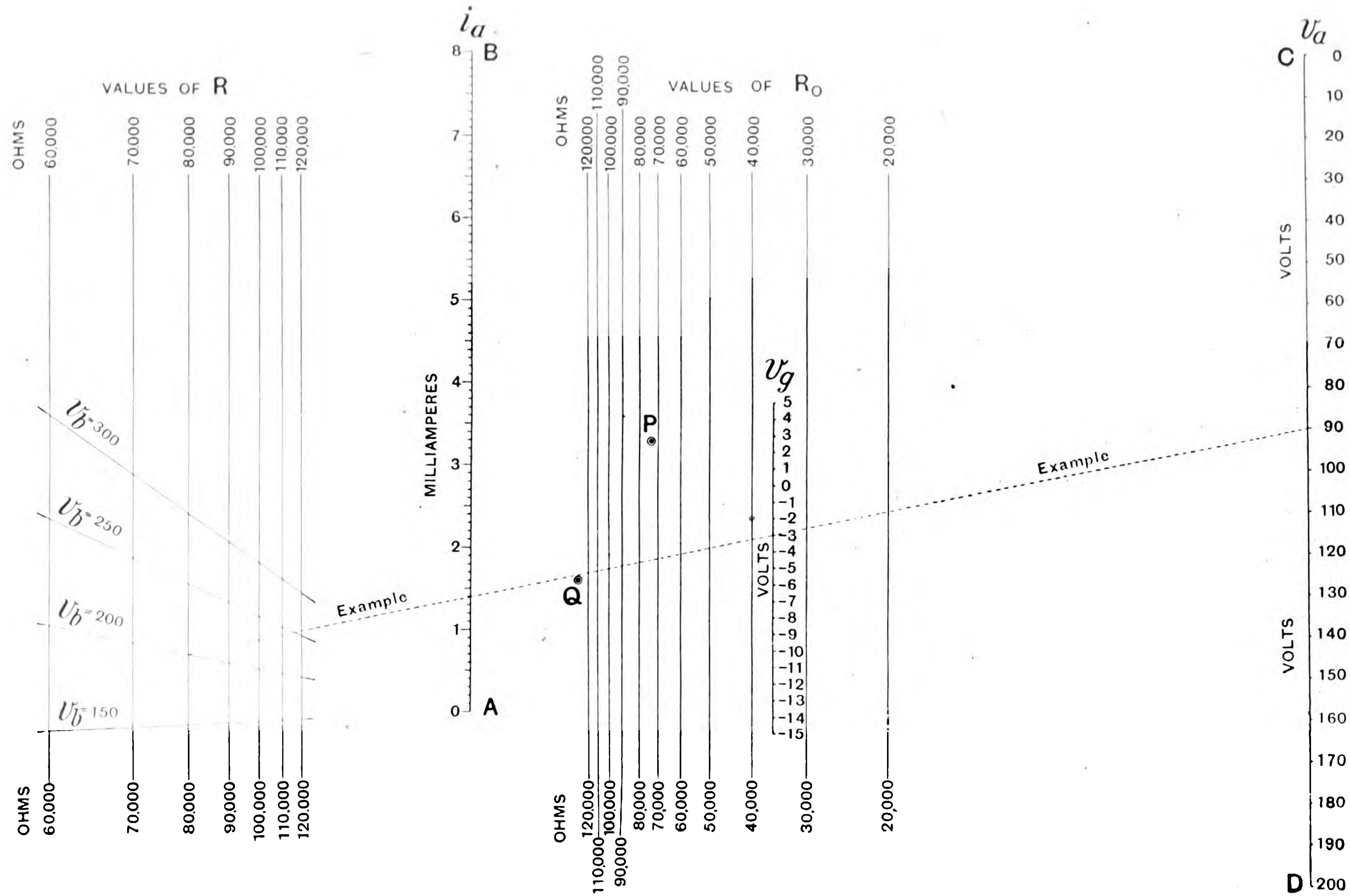


Fig. 2. *The example line shows that, for the particular valve illustrated, using an H.T. battery of 200 volts and an external resistance of 80,000 ohms, an anode current of 1.4 milliamperes flows when V_g = — 3 volts; the actual anode voltage is 90, the voltage drop in the resistance being 110. The internal A.C. resistance is 35,000 ohms. For other valves other scales of V_g may be drawn in.*

of different valves under different conditions of operation may thus be compared with a minimum of effort. This circumstance alone should, the writer ventures to think, commend the alignment characteristic to the attention of all serious experimenters. When constructed the diagram is simplicity to use, and while its preparation entails a little calculation, the labour involved will be seen to be very small in proportion to the results which are achieved.

The diagram itself (see Fig. 2) consists of two parallel scales, AB and CD, drawn at any distance apart, and graduated respectively to represent values of anode current and anode volts. These graduations, which may start from any point on the lines, are set out in opposite directions to any convenient scale of amperes and volts. In the present diagram, the scale AB is shown graduated in milliamperes for convenience, this being a standard measure of anode current. The scales being thus arbitrarily chosen, let r denote the ratio of the length which represents 1 amp on scale AB to that which represents 1 volt on scale CD. It will be seen that r is a very large number; in the case illustrated in Fig. 2 it has been taken as 20,000.

Besides the two main scales AB and CD, certain other lines parallel to these are now drawn, whose distances from scale AB are computed as follows: Taking the distance between AB and CD as unity, the lines to the left of AB are distant from it by the fraction $r/R—r$ where the values of R in ohms correspond with the range of external anode resistances likely to be used with the valves. The lines to the right of AB are distant from it by the fraction r/R_0+r, the values of R_0 corresponding to the range of internal anode A.C. resistances likely to be found among the valves used. Having drawn in the lines to represent the selected values of R and R_0, the alignment diagram is now prepared to receive the actual data concerning the valves with which it is proposed to deal.

As pointed out above, the present procedure is intended to deal only with the linear field of the characteristic. We shall therefore exclude for our present purpose all observations which fall outside this field. Using one particular valve, let us note all the pairs of values of i_a and v_a which are associated with a certain grid voltage v_g. If now such corresponding values of i_a and v_a be sought on the scales AB and CD, the lines joining them will be found to intersect each other in exceedingly contiguous points. So close, indeed, will these points of intersection lie (for data within the linear field) that the position of an ideal point which should represent them all can be plotted with reasonable accuracy. For the purpose of obtaining the position of this point, the intersecting lines should be drawn in pencil only; the point itself may be pricked in,

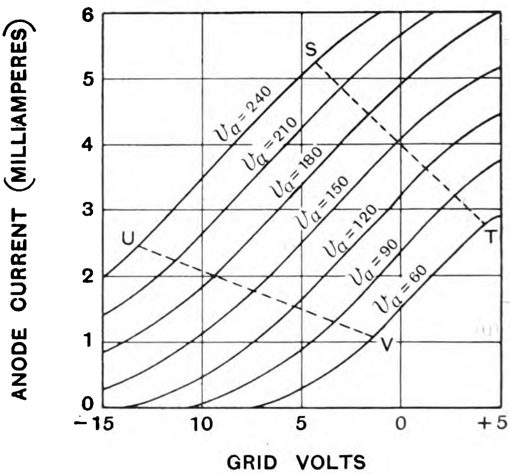


Fig. 3.

when the lines may be erased. Other points to represent other values of v_g are found in the same way within similar polygons of error, and if the work has been carefully done, and the observations plotted kept within the bounds of the linear field, it will be found that each of these v_g points lies on a straight line parallel to the scales AB and CD. (This fact may also be found helpful in plotting the actual positions of the v_g points, forming yet another line among the various polygons of intersection.) Upon the line thus found may now be entered a complete scale of values for the required range of v_g. This scale should be linear; *i.e.*, equidifferent values of v_g should be equidistant on the scale. The graduations should also lie in the opposite sense to those on the scale CD for anode volts.

In Fig. 2 such a v_g scale for a particular valve has been shown. For purposes of

comparison, the v_g–i_a characteristic curves of the same valve are reproduced in Fig. 3. In this graphical characteristic, the curves are drawn at intervals of 30 volts of anode potential. The limits of the linear field may conveniently be indicated by the dotted lines *ST* and *UV*.

The three scales now shown on the diagram of Fig. 2 provide a representation by alignment of the variations in the quantities v_a, v_g and i_a within the linear field of the valve in question. This is to say that within that field, they represent the equation,

$$i_a = \frac{v_a + \mu_0 v_g - v_0}{R_0}$$

We shall now show how the constants R_0, μ_0 and v_0 may be simply indicated by means of the alignment diagram. Firstly, the position of the v_g line among the mesh of R_0 lines affords a direct measure of the value of R_0 for the valve. Thus in the diagram of Fig. 2, the internal anode A.C. resistance is read as 35,000 ohms. If greater accuracy is required, the value of the ratio which the distance of the v_g scale from *AB* bears to the distance between *AB* and *CD* may be ascertained by direct measurement. By equating this ratio to the expression r/R_0+r, the value of R_0 may be more precisely ascertained. Next the valve amplification factor μ_0 is obtained by rotating a straight edge about any fixed point on the scale of i_a. If in its travel it is allowed to pass over a range of 1 volt on the v_g scale the corresponding number of volts passed over on the v_a scale determines the value of μ_0. In practice, it is well to allow the travelling line to pass over several volts on the v_g scale, dividing the corresponding range for v_a by this factor to obtain μ_0. In Fig. 2 it will be found that such a line, pivoted anywhere on *AB*, and traversing a range of 10 volts on the v_g scale, will pass through 110 volts on the v_a scale. Hence μ_0 for this valve is 11. Lastly, to arrive at the amount of the space charge effect v_0, a line is drawn through the zero values on the i_a and v_g scales. This line will meet the scale of anode volts in the value of v_0 for the valve.

Before going on to consider further applications of the alignment diagram, it may be well to supplement the above description with a mathematical proof of the properties so far considered. We shall suppose in what follows that on the scale *AB* a distance of α inches represents 1 ampere while on the scale *CD* a distance of β inches represents 1 volt. Then the fraction α/β is equal to r, the ratio between these scales already considered.

We shall first prove that the v_g points lie on a line parallel to *AB*, and distant from it by the fraction r/R_0+r. In Fig. 4, let *P* denote any value i_a of anode current on the scale *AB*, and let *Q* represent the corresponding value v_a of anode voltage on the scale *CD* which is obtained with a certain definite value of grid voltage, v_g. Keeping the

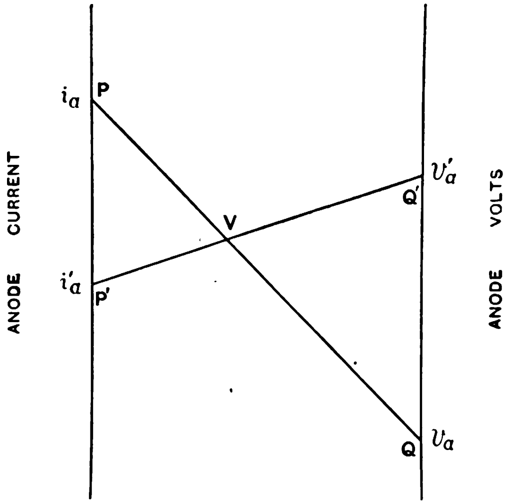


Fig. 4.

value of v_g constant, let *P′* denote a different value of anode current i_a', and let *Q′* represent the corresponding value of anode volts, v_a'. Let *PQ* and *P′Q′* meet in *V*. Then, we have,

$$\frac{PP'}{QQ'} = \frac{\alpha\,(i_a' - i_a)}{\beta(v_a - v_a')}$$

But, when v_g is constant, the internal A.C. resistance of the valve is defined by the ratio of a change in v_a to the corresponding change in i_a. Hence,

$$\frac{PP'}{QQ'} = \frac{r}{R_0}$$

But, by geometry, the ratio PP'/QQ' is equal to the ratio of the distances of *V* from the lines *PP′* and *QQ′*. Therefore, the ratio of the

distance of V from PP' to the total distance between the scales is,

$$\frac{PP'}{QQ' + PP'} = \frac{r}{R_0 + r}$$

The position of the point V is thus situated at a distance from AB depending solely on R_0, and is invariant with regard to the values of v_g. For all such values of v_g, therefore, the points V will lie on a straight line at the above distance from AB.

Next, we shall show that the v_g points on this line form a linear scale. In Fig. 5, let A represent the zero point on the scale of anode current, and let B represent the current value i_a. Let C on the scale of anode volts represent v_0, the space charge voltage, and D represent the actual anode voltage v_a. Let the line FKH be drawn dividing the distance between AB and CD in the ratio r/R_0. Then its distance from AB is to the distance between AB and CD as $r / R_0 + r$, and the v_g points will lie along it, as shown above. Let AC meet FKH in H, and BD meet it in K. Also draw BE parallel to AC to meet HK in F and DC in E. Then,

$$AB = a\, i_a$$
$$CD = \beta\,(v_a - v_0)$$

$$\frac{FK}{ED} = \frac{FH - HK}{EC + CD} = \frac{AB - HK}{AB + CD} = \frac{a i_a - HK}{a i_a + \beta(v_a - v_0)}$$

But $\dfrac{FK}{ED} = \dfrac{r}{R_0 + r}$ by construction.

$$\therefore \quad HK = a i_a - \frac{r}{R_0 + r}\left\{a i_a + \beta(v_a - v_0)\right\}$$

$$= \frac{a}{R_0 + r}\left\{i_a R_0 - (v_a - v_0)\right\}$$

But from equation (1)

$$i_a R_0 - (v_a - v_0) = \mu_0 v_g$$

Hence,

$$HK = \frac{a\mu_0 v_g}{R_0 + r} \quad \ldots \quad \ldots \quad (2)$$

i.e., the distance HK is proportional to v_g. But in equation (2) when $v_g = 0$, $HK = 0$, *i.e.*, K coincides with the fixed point H. Thus the point H represents $v_g = 0$, and other values of v_g are represented by points whose distances from H are proportional to their amounts. Moreover, the scale to which these values appear on the diagram is 1 volt $= a\mu_0/R_0 + r$ ins., from equation (2). To prove the construction for μ_0, we may note that a movable line pivoted at any point on AB will traverse $R_0 + r/r$ ins. on CD for 1 in. traversed on HK. If, therefore, it traverse $a\mu_0/R_0 + r$ ins. on HK, it will traverse $a\mu_0/r = \beta\mu_0$ ins. on CD., *i.e.*, for 1 volt on HK it passes through μ_0 volts on CD.

We may now proceed to show how the alignment diagram of Fig. 2 can be made to take account of the effect of an external resistance load, when this is introduced into the plate circuit.

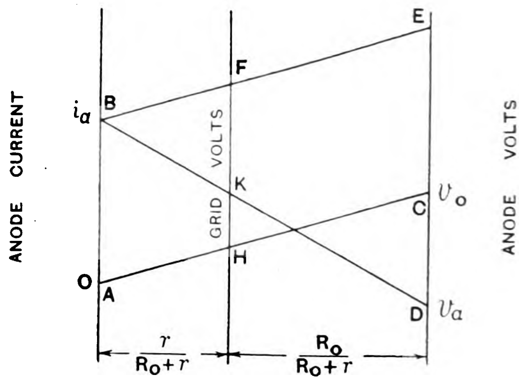


Fig. 5.

Taking on the scale of anode volts the point representing v_b, the value of the H.T. battery voltage, we join it to the zero of the i_a scale and produce till it meets the external resistance line corresponding to the required value R. This line need not actually be drawn, but the resulting point should be marked. Using this point as a pivot, it will now be found that any straight line drawn through it will meet the scales of i_a, v_g and v_a in points whose graduations correspond to the working conditions of the valve with load R within the linear field. For example, if a definite anode current be required, its value on the i_a scale is joined to the pivot R point. The necessary values of grid and anode voltage to produce this current are then read off in alignment on their appropriate scales, the voltage drop in the resistance being measured by the difference of v_b and v_a on the scale of anode volts. It is evident that the effect of varying the external resistance may be traced with ease, the various pivotal points for any given H.T. battery voltage being found on the various R lines as above explained. In passing, it is worth

noticing that these pivotal R points are in no way dependent upon the particular valve concerned, but merely upon the values of external resistance and battery voltage in use. It is thus possible to represent different values of v_b by a pencil of lines drawn through the zero point of the i_a scale to meet the mesh of external resistance lines. Upon the resulting network, the positions of the pivotal points for resistance load working can be sought with extreme facility. In Fig. 2, a pencil of four lines has been drawn to represent values of v_b at intervals of 50 volts. Such a network remains the same for all valves, an important feature when it is desired to compare the performance of different valves under similar conditions of H.T. potential and loading.

In the diagram of Fig. 2, the example line is shown passing through the values $v_b=200$, $R=80{,}000$. For the valve in question, if these values are used, an anode current of 1.4mA is seen to be obtained with a grid voltage of -3, while the same line further indicates that under these conditions the actual potential of the anode is 90 volts.

A proof of the alignment properties of the diagram for external resistances may now be given. In Fig. 6, let A represent the zero point on the scale of anode current, and let B represent the current value i_a. Let D

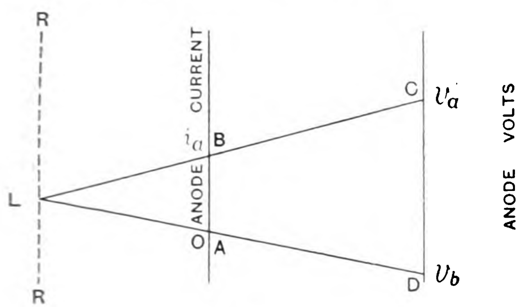


Fig. 6.

on the scale of anode volts represent v_b, the H.T. battery voltage, and let the line DA produced meet the external resistance line of the value R in the pivotal point L. Join LB, and produce it to meet the scale of anode volts in C. Then we must show that the point C represents the value v_a of anode potential. Now since, by construction, the distance of L from AB is to the distance between AB and CD as $r : R - r$, the distance of L from AB will be to its distance from CD as $r : R$.

Therefore, $AB : CD = r : R$

But $AB = \alpha\, i_a$ ins.

$\therefore$ $CD = \alpha i_a \,.\, R/r$ ins.

$= \beta R i_a$ ins.

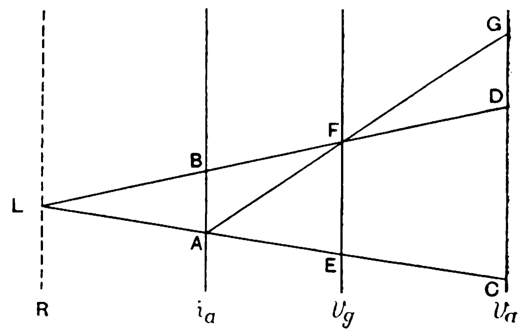


Fig. 7.

Since, however, in the external anode circuit, the voltage drop across the resistance is equal to the product of the current and the resistance (Ohm's Law), we have

$$Ri_a = v_b - v_a$$

so that

$$CD = \beta\,(v_b - v_a) \text{ ins.}$$

Thus the distance CD measures the difference $v_b - v_a$ on the scale of anode volts. Now, the point C must always lie *above* D (because B lies above A), and thus its value must always be *less* than v_b. Hence the point C represents v_a.

We now pass on to note the effect which the presence of an external resistance load has upon the voltage magnification obtained. The moving line used above to find the value of μ_0 was pivoted on any point on the scale of i_a. Using a resistance R, however, the line is pivoted about any point on the R line, and the intercept on the v_a scale for a change of 1 volt on the v_g scale read as before. The value of μ so obtained is obviously smaller than that of μ_0. To prove that it is actually $R/R_0 + R$ of μ_0, we may reason as follows:—

In Fig. 7 let EF represent any interval of 1 volt on the v_g scale, and take L, any point on the external resistance line, R. Join LE and LF, and let them meet the i_a scale in A and B, and the v_a scale in C and D respectively. Join AF, and produce it to meet the

v_a scale in G. Then it has been shown above that the distance CG represents μ_0 volts. We have now to show that CD represents μ volts.

We have, by the geometry of similar triangles,

$$\frac{GC}{FE} = \frac{AC}{AE} = \frac{R_0 + r}{r} \qquad \dots \qquad \dots \qquad (\xi)$$

$$\frac{FE}{BA} = \frac{LE}{LA} = \frac{LA + AE}{LA} = 1 + \frac{AE}{LA} =$$

$$1 + \frac{AE/AC}{LA/AC} = 1 + \frac{r/R_0 + r}{r/R - r} = \frac{R_0 + R}{R_0 + r} \quad \dots \quad (\eta)$$

$$\frac{BA}{DC} = \frac{LA}{LC} = \frac{LA}{LA + AC} = \frac{LA/AC}{(LA/AC) + 1} =$$

$$\frac{r/R - r}{(r/R - r) + 1} = \frac{r}{R} \qquad \dots \qquad \dots \qquad (\zeta)$$

Multiplying together the right and left hand sides of equations (ξ), (η) and (ζ), we have

$$\frac{GC}{FE} \cdot \frac{FE}{BA} \cdot \frac{BA}{DC} = \frac{GC}{DC} =$$

$$\frac{R_0 + r}{r} \cdot \frac{R_0 + R}{R_0 + r} \cdot \frac{r}{R} = \frac{R_0 + R}{R}$$

i.e., $$DC = GC \times \frac{R}{R_0 + R}$$

Thus, DC represents μ volts.

The voltage magnification obtained with an external resistance is, of course, independent of the H.T. battery voltage used. For this reason, any point on the R line may be used as pivot when finding the value of μ. Using an external resistance of 80,000 ohms with the valve of our example, the effective valve magnification is easily seen from Fig. 2 to be 7.6, the percentage modification being thus 69 per cent.

The discussion has so far been limited to the case of one particular valve, and it has been shown how its various constants R_0, μ_0 and v_0 may be readily ascertained, and how its performance within the linear field is modified by the inclusion of an external anode resistance. It should be remembered that the fundamentals of the diagram are the i_a and v_a scales and the R_0 and R lines. The scale of v_g is peculiar to the individual valve; to other valves different scales of v_g will correspond, and may also be shown upon the diagram as vertical lines situated at appropriate positions for R_0. These other scales of v_g will all be linear, though they are quite distinct, their graduations bearing no relation to each other. On the facility with which the performance of different valves may be thus compared under various working conditions, the writer would base his chief claim for the use of the method in amplification work.

Throughout this article, care has been taken to emphasise the fact that the results obtained from the alignment diagram are only true within the linear field of the valve in use. It is natural to inquire if any limitations are imposed on the diagram by reason of this condition. To answer this question fully would take us too deeply into the theory of alignment for our present purpose, which is primarily that of exposition. Without attempting anything in the nature of reasoned proof, however, the writer may answer it by alluding briefly to the underlying principles of the alignment process. This is virtually an application of the "Principle of Duality," with which those who are acquainted with Modern Geometry will be familiar. Roughly speaking, this principle enunciates that to all theorems concerning points and straight lines, there correspond reciprocal theorems in which these entities have been interchanged, so that where before we had a theorem concerning a set of straight lines and points of intersection, we now have a corresponding theorem dealing with a set of points and the straight lines joining them. If the points in the first theorem were collinear, the corresponding lines in the second are concurrent and *vice versa*.

In its simplest form, the alignment method may be said to apply this "Principle of Duality" to the Cartesian representation of straight lines, which thus become points on the alignment diagram. For example, the straight portions of the characteristic curves of Fig, 3 become points on the v_a scale of Fig. 2. Again, the coordinate axes of the graph, representing zero values of v_g and i_a are replaced by the zero points on these scales in Fig. 2. Further, any point on the coordinate surface can be identified with a straight line on the alignment diagram which passes through those points on the scales corresponding to the coordinate values of the point. Now, it was found convenient to delimit the linear field of the characteristic curves in Fig. 3 by the lines ST and UV.

To these two lines, therefore, should correspond two definite points on the alignment diagram, and these are indicated on Fig. 2 by P and Q respectively. If the positions of these two points are known, we may apply the Principle of Duality to the delimitation of the linear field by "translating" the definition of the Cartesian field to suit the reciprocal diagram. For amplification, it is known that all working points on the graphical characteristic lie between the lines ST and UV. This statement is replaced for the alignment diagram by the equivalent assertion that *all working lines must lie between the points P and Q.* Here, then, is the required condition which every movable or index line applied to the diagram must fulfil, in order that it may represent a relation falling within the linear field of the valve.

It remains to indicate how the positions of P and Q are to be found. In Fig. 3, let S, T, U, V represent the limits of the linear field for ordinary amplification work. Let us suppose that the coordinates of these four points have respectively the values (v_{g1}, i_{a1}), (v_{g2}, i_{a2}), (v_{g3}, i_{a3}), (v_{g4}, i_{a4}). On the alignment diagram of Fig. 8, draw a line s joining the points v_{g1} and i_{a1} on their respective scales, and also a line t joining v_{g2} and i_{a2}. The intersection of these lines s and t gives the point P which represents on Fig. 8 the straight line ST of Fig. 3. Again on Fig. 8 draw a line u through the values v_{g3} and i_{a3}, and also v through v_{g4} and i_{a4}. Then the intersection Q of u and v represents the line UV of Fig. 3. The proof is complicated, and may be left to those readers who are conversant with projective geometry.

It may not be superfluous to devote a few words in conclusion to the practical working of the diagram. For the elucidation of the principles on which it is founded, it was assumed above that the quantities R_0, μ_0 and v_0 are true constants. This, in fact, is not strictly the case. Within the linear field itself these quantities, and especially R_0, are subject to variation. The effect of this upon the alignment diagram is that instead of the grid volts scale being a vertical line, it is in general slightly curved. This, of course, indicates very conveniently the variation of R_0 with grid voltage, a variation quite well established within the linear field. Strictly speaking, of course, R_0 is not a definite function of grid voltage alone, being subject also to slight variation with anode voltage. Within the linear field, however, this latter variation is negligible. The crux of the matter lies in the precise delimitation of the linear field. The extent of the region within which the curves on the Cartesian diagram may be regarded as "straight" is entirely arbitrary, and the limits assigned may vary for different purposes. These limits once fixed, however, it is possible to obtain on the alignment diagram the positions of optimum points to represent values of

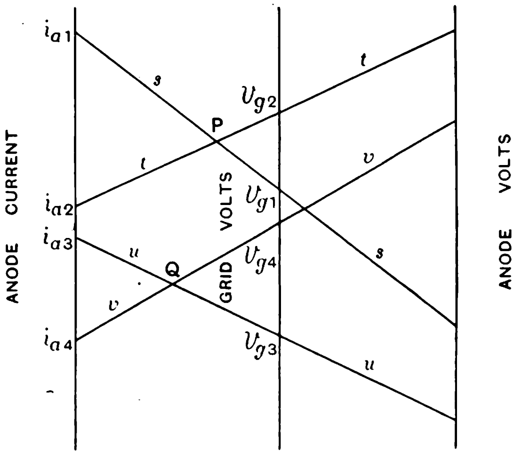


Fig. 8.

grid voltage in the manner described, the curve through which will support the v_g scale. Beyond these limits, of course, the method is not available.

The unique possibilities afforded by the diagram of indicating variation in anode A.C. resistance will not escape those experimenters who wish to follow approximately the effect of this important factor in amplifying work. There is, at present, a regrettable tendency on the part of manufacturers to quote a fixed value of R_0 for their valves, and it is thought that the ease with which the variations in this quantity may be traced will be found not the least commendable property of the alignment diagram.

It may be remarked that the foregoing is by no means an exhaustive account of the uses to which the alignment diagram may be put. In particular, nothing has been said regarding its many "inverse" functions.

For example, we have seen that for the particular valve illustrated in Fig. 2, to obtain 1.4mA with —3 volts on the grid, an H.T. supply of 200 volts together with an external resistance of 80,000 ohms are used. If the H.T. supply available is 250 volts, the value of the resistance necessary is read at the intersection of the same index line with the line $v_b=250$, and is seen to be 115,000 ohms. In each case the actual anode potential is 90 volts. The facilities offered by the diagram in the checking of experimental results need not be enlarged upon, and many other such inverse uses will present themselves to the reader who may be disposed to construct such a chart for his own valves. Enough has been said here in indication of a linear field characteristic which promises to be as useful practically as it is interesting theoretically.

Book Review.

ELECTRICAL CONDENSERS. By Philip R. Coursey. Pp. 637+xxiv. Price 37s. 6d. net. (Sir Isaac Pitman and Sons.)

In his preface to this book Mr. Coursey tells us that its purpose is to dispel the idea that condensers are merely fragile pieces of apparatus to be found in physical laboratories, and to show that they are important components of many large electrical installations, and that their industrial importance is very great and rapidly growing. There is no doubt that the book will achieve this object. A mere glance at a few of its five hundred illustrations will convince the reader, and he cannot fail to be impressed by the fact that here is a large book of over six hundred pages dealing almost exclusively with condensers.

For the most part, the book is encyclopædic in character. The construction of a large number of condensers of all types is described in some detail. These include small fixed and variable condensers for radio receiving circuits, large condensers used in transmitting circuits, condensers for the protection of high voltage transmission lines, and those for the improvement of the power factors of A.C. circuits; condensers with dielectrics of air, glass, paper, mica, oil, cellon, and, in short, condensers of almost every type that has ever existed. Even the synchronous condenser is included. Wireless enthusiasts will probably be interested in the chapter dealing with the scores of variable air condensers of different types. There are many good illustrations, not only of condensers, but also of the machinery used for making them, installations in which they are used on a large scale, and so on.

The purely scientific side of the subject has naturally received some attention, and in this connection the book is remarkable for the bibliography of some two thousand references which occupies its last hundred pages. The research worker will find this very valuable, although it seems somewhat out of keeping with the rest of the book. The fact is that it requires an expert to sort out the wheat and chaff in such an enormous list of references, whereas the book itself is evidently not primarily written for the expert. In many cases the scientific treatment is very superficial. For example, in dealing with the Weston microfaradmeter, we are told that "it makes use of a moving coil movement with pointer moving over a scale graduated in microfarads." We are then given a photograph of the instrument, and another of a number of girls using it in a test room, and the subject is dismissed. Again, in connection with the tuning of vibration galvanometers, the only information given is that it is done "by the rotation of the knob at the right hand side of the instrument" (illustrated). These are extreme cases, but there is rather a tendency when dealing with matters of scientific interest to put off the reader with a list of half-a-dozen references, when what he really wants is a short explanation. One would have preferred to see the subject of "earth capacities" and the screening of condensers treated in rather greater detail, and also the definition of capacity itself. Without a thorough understanding of these points it is impossible to apply in practice the formulæ for the capacities of spheres, etc., given in Chapter VI.

It is also a little disappointing that Mr. Coursey has not given us more of the benefit of his experience in a rather more critical treatment. He has usually been content to describe without comment. The secrets of good construction are certainly not revealed to us. We are even told that in standard mica condensers "mica and copper foil electrodes are commonly used with *shellac*, or a similar adhesive, to maintain the condenser in a rigid condition." Did Mr. Coursey write this with his tongue in his cheek?

The book contains valuable lists of the dielectric constants, dielectric strengths, resistivities and power factors of a large number of dielectrics. Some of the curves published by Curtis giving the properties of typical mica and paraffined paper condensers would have formed a valuable addition to this.

While the book does not satisfy all our needs, we must not lose sight of the fact that it is a mine of information on all matters relating to condensers, that it is well up to date, and so well provided with references that it will put us into touch with practically all there is to be known on the subject. For this we are grateful.

L. HARTSHORN.

Battery Eliminators

Or, Appliances for the Operation of Radio Receiving Circuits by Energy Derived from Electric Supply Mains.

Paper read by Messrs. P. R. COURSEY, B.Sc., M.I.E.E., and H. ANDREWES, B.Sc., before the Wireless Section, I.E.E., on 6th April, 1927.

ABSTRACT.

1. Introduction.*

THE modern radio receiver using thermionic valves requires to be energised from three distinct electrical sources, *i.e.*, (*a*) High tension, (*b*) Low tension, and (*c*) Grid bias. For all three a sensibly steady D.C. supply is necessary, the differences between them lying mainly in the voltage and current that they must deliver. The frequent replenishing and recharging of batteries has created a demand for apparatus which will replace them and provide equivalent voltages and currents derived from the public electric supply mains.

2. Scope of the Paper.

The purpose of the paper is to discuss the essential requirements of this class of apparatus, to consider the main features of its design and application, and to show the type of results that are obtainable in its use and in what direction further advances are required. A great deal of radio apparatus has in the past suffered from a lack of anything in the nature of real "engineering" design. The more extended use of appliances to supply these voltages may thus in time reflect on the design of the receiver itself from the point of view of insulation and general quality of construction. To some extent also it may ultimately affect the electrical design itself on account of the higher voltages made available for general use, without undue operating or maintenance expense.

3. Radio Supply Appliances.

The name of "Radio Supply Appliances" is suggested (in lieu of the more usual term "battery eliminators") as being of broader application. It is pointed out that a complication arises due to the voltages having a common connection at the valve filaments and also in the supply mains. Fig. 1 is given as illustrating a theoretical arrangement rather than a possible and actual one.

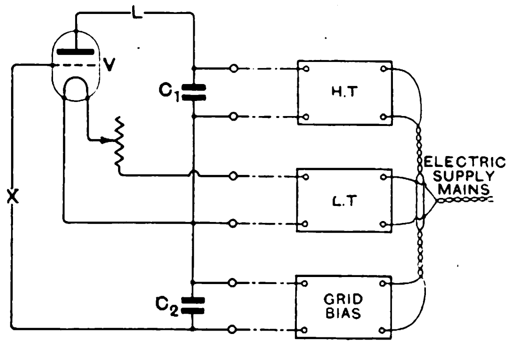


Fig. 1.

4. General Principles.

These are discussed only very briefly. It is pointed out that the precise arrangements depend in the first place on whether the supply is D.C. or A.C. In the latter case, some form of rectification must be provided, and that even the best D.C. supply circuit requires smoothing before application to the receiver.

5. H.T. Supply Appliances.

The first essential element of the H.T. appliance is a filter to perform the smoothing combined with a potentiometer or equivalent device for subdividing the applied voltage into one or more parts. For A.C. supply circuits rectification must also be added. Fig. 2 is given as showing the essential elements of a H.T. supply appliance for D.C. mains. The combination of C_1 L_1 and C_2 acts as a filter to suppress currents of higher

* The authors' original section numbers and figure numbers are adhered to throughout this abstract.

frequencies and to allow the lower frequency and zero frequency (direct current) to pass, the general form of the filler being of the "low pass" type. A further inductance and condenser may be introduced to improve the filtering efficiency.

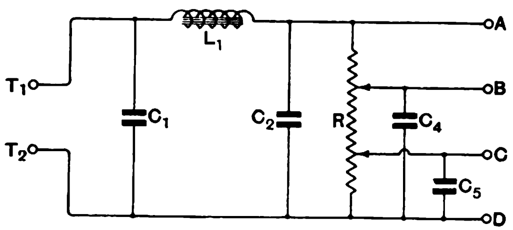


Fig. 2.

6. Adjustment of Output Voltage.

With a 200-240-volt supply, about 200 v. will be available across AD, the difference being the voltage-drop due to the resistance of the chokes. Intermediate voltages may be obtained by tappings such as B and C, while it is desirable to have additional by-pass condensers—of at least 1μF—across these additional tappings to prevent excessive coupling between valves when more than one valve stage is operated from the same point. An alternative arrangement of voltage taps is shown in Fig. 4. This

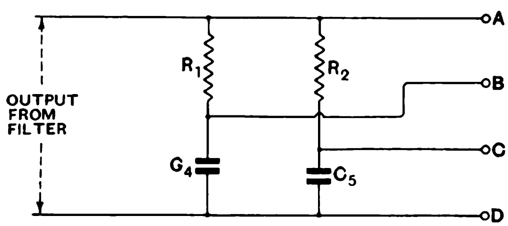


Fig. 4.

arrangement has the advantage of somewhat reducing the coupling between valves, since the total H.T. current is divided through different resistances. There is, however, somewhat greater voltage variation of the points B and C with varying load.

7. H.T. Filter.

The mathematical theory of filter circuits is not dealt with, the authors giving only a few general remarks. It is pointed out that, with a rectified A.C. supply, the input condenser is involved in the storage of the rectified impulses during a part, at least, of each cycle. It should therefore be of reasonably large capacity. With D.C. supply the ripple is not much (if at all) affected by this condenser. In some cases advantage has been taken of the fact in the manufacture of D.C. apparatus, by omitting the first condenser, but, in other cases, probably for the sake of simplicity or uniformity in manufacture, the same arrangement of filter condensers is used for both D.C. and A.C.

8. Design of H.T. Filter.

There are, in general, three electrical factors affecting the design of the filter. The commercial design is, to a greater or less extent, a compromise between considerations of electrical efficiency and cost. These factors are :—

1. The internal resistance of the chokes as affecting the "regulation" of the apparatus on load.

2. The resonance frequency of the filter, affecting its efficiency in removing "hum."

3. The output impedance at audio frequencies, controlled mainly by the output condenser capacity, and affecting the load which may be drawn from the filter without producing oscillation in the receiver.

The single filter circuit, of Fig. 2, may be regarded as a resonant circuit of L_1 and C_2 in series, and it is stated that the resonance curve of this filter was found to be unaffected by the capacity of the input condenser C_1, when subjected to applied alternating voltages at various frequencies. The load is effectively a resistance across C_2, damping this resonant circuit. The behaviour of various filtering arrangements are shown by plotting against frequency the ratio of the voltage V_0 across C_2 and the input voltage V_i, across C_1 of Fig. 2. A typical curve is shown in Fig. 6.

Figs. 7, 8, 9 and 10 show the effect of the different electrical dimensions given.

A group of characteristics for a double filter is shown in Fig. 11. Some of these curves show a subsidiary bump, which

might have a serious effect if it occurred near 50 or 100 cycles. The possibility of this emphasises the need for plotting the characteristics of any filter that is proposed for use in an H.T. supply appliance.

with a single detector appears to be much the same as when one or two L.F. stages are added. It appears to the authors that quite satisfactory results may be expected if the ripple voltage is of the order of 0.1 volt in

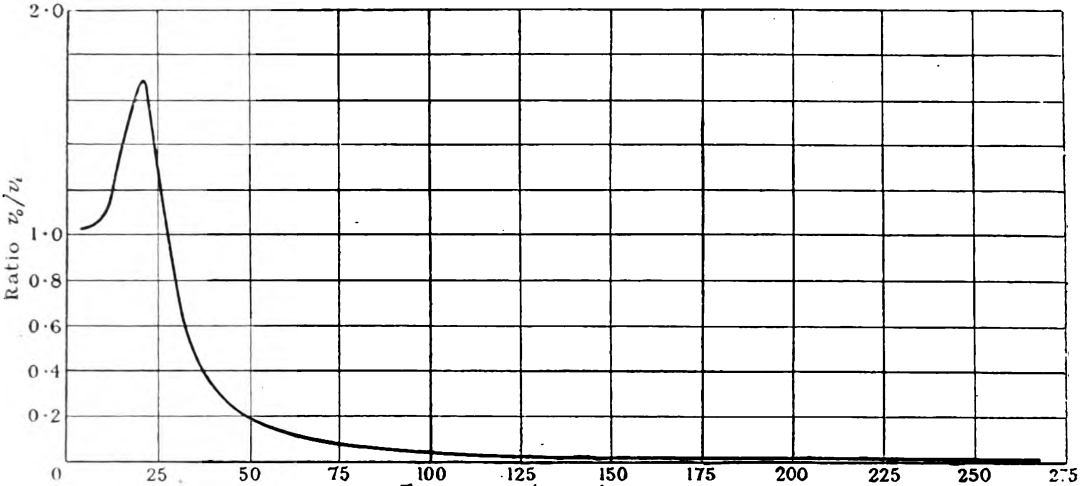


Fig. 6.

9. Permissible Ripple Voltages.

It is stated that experiments have shown the greatest source of disturbance to be the detector valve. With a given ripple voltage in the H.T. supply, the intensity of the hum

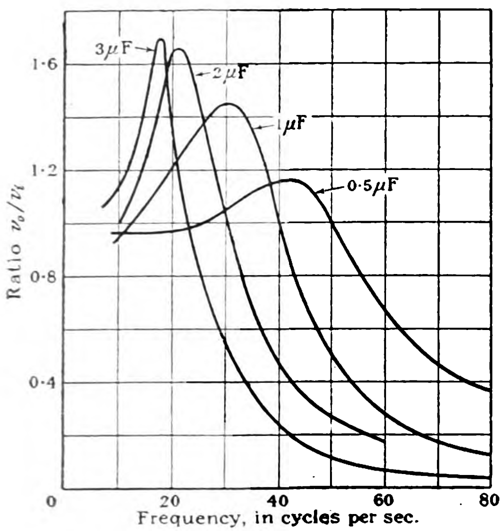


Fig. 7.

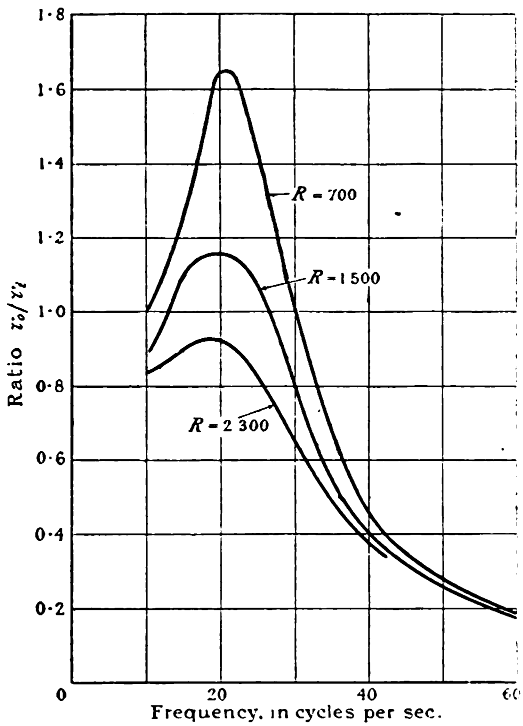


Fig. 8.

the H.T. circuit. Even with comparatively weak signals 0.2 volt of ripple is not particularly noticeable except during silent periods. With loud signals 0.25 to 0.4 volt does not particularly mar reception, although the hum becomes quite noticeable during silent periods. One volt of ripple appears to the authors to be excessive and could be improved by better design of the appliance.

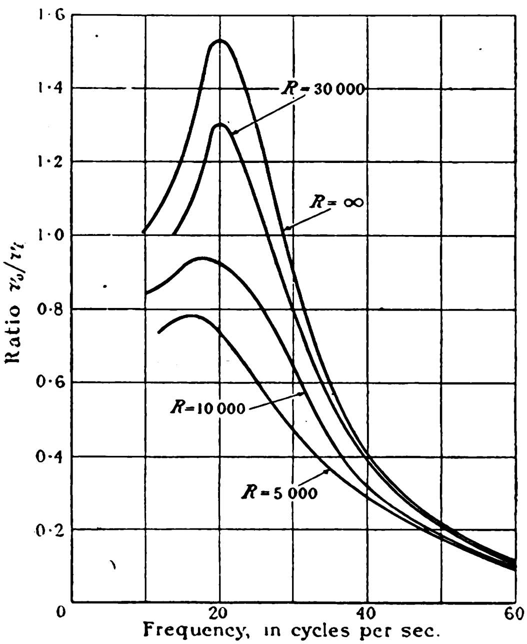


Fig. 9.

10. Rating of H.T. Supply Appliances.

It is suggested that the time is ripe for the formulation of a definite scheme of rating these devices. It appears to the authors that possibly two or three of the following characteristics might suffice for the purpose :—

1. The percentage regulation of the output voltage at a stated output current, *e.g.*, 1mA.

   This quantity
   $$= \frac{100 \times \text{voltage-drop at 1mA output.}}{\text{Initial voltage at zero output.}}$$

2. The internal impedance of the appliance expressed in ohms.

   $$\text{This quantity} = \frac{1{,}000 \times \text{voltage-drop.}}{\text{Load current, in mA.}}$$

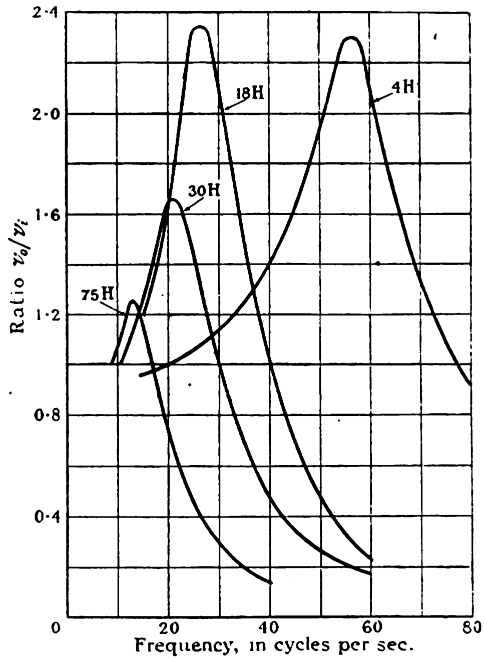


Fig. 10.

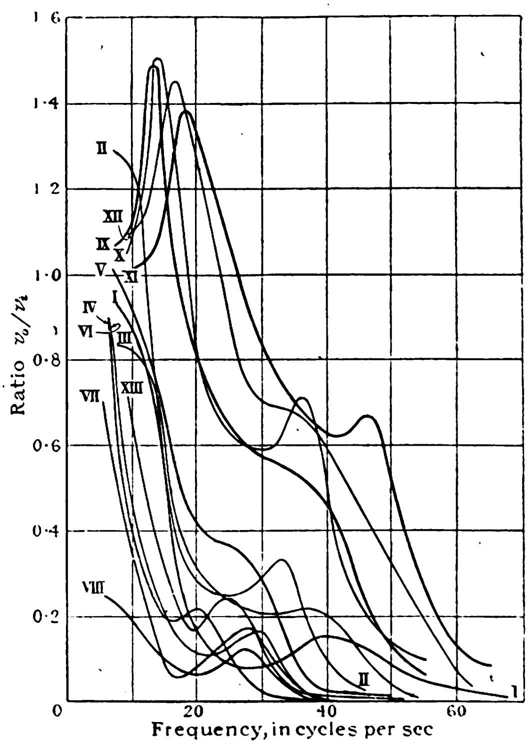


Fig. 11.

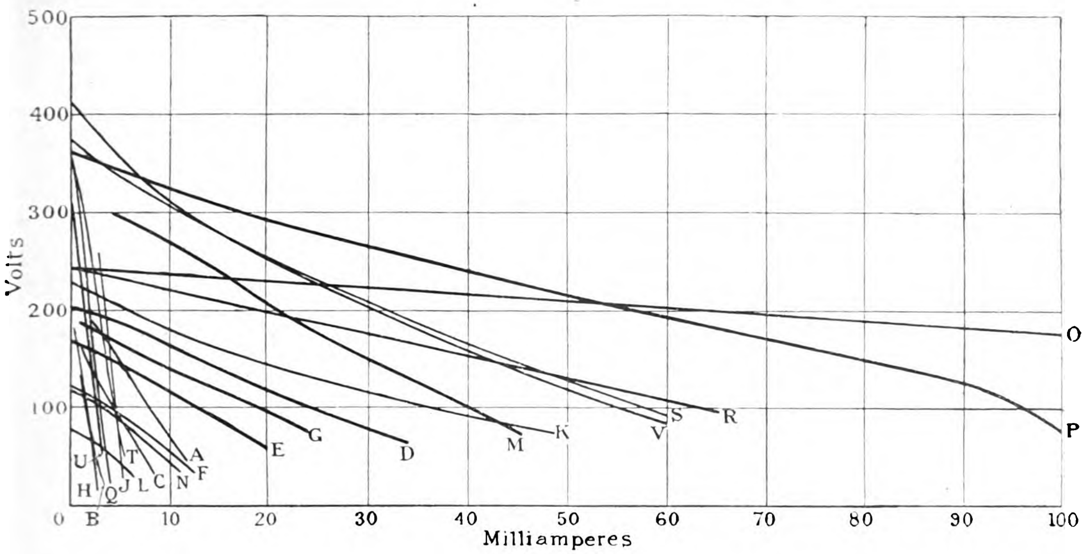


Fig. 12.

3. The useful output, expressed in mA for a fixed permitted voltage-drop, say, $33\frac{1}{3}$ per cent. from the initial voltage.

4. The audio-frequency impedance of the output circuit of the appliance measured at some stated frequency, *e.g.*, 500 cycles per sec.

Some idea of the extent of the variation of these quantities for a number of commercial appliances is shown in Table I., the name of the makers not being given. The variation of output voltage and current is also brought out in Fig. 12. These emphasise the wide variety in designs which are met with, and show that finality in design cannot yet be said to have been reached.

11. Measurement of Output Characteristics.

The load of an ordinary type of moving coil voltmeter rendering it nonpermissible, the use of a "Unipivot" galvanometer with a scale of 0 to 120μA is recommended with a series resistance of 2 megohms. A voltmeter of this type also enables a reasonably true measure to be made of the output voltages under working conditions.

TABLE I.

MEASURED OUTPUT COEFFICIENTS OF VARIOUS COMMERCIAL H.T. SUPPLY APPLIANCES.

Reference to Fig. 12.	Regulation for load of 1mA	Internal Impedance.	Effective output for voltage drop of $33\frac{1}{3}$ per cent.	Audio-frequency impedance of output circuit.
	%	ohms.	mA	ohms.
A	8.69	19,000	4.0	160
B	30.6	50,000	1.0	160
C	9.65	16,000	3.6	—
D	1.98	4,167	16.2	320
E	3.4	6,000	9.6	—
F	5.4	6,500	15.8	—
G	2.67	4,375	14.0	160
H	35.79	68,000	0.9	320
J	19.8	100,000	2.0	160
K	1.25	2,667	25.2	318
L	9.5	8,200	3.2	265
M	1.7	5,700	19.3	160
N	6.4	7,800	5.3	—
O	0.27	670	121.0	170
P	1.4	5,000	49.0	170
Q	26.7	100,000	1.3	490
R	1.1	2,500	34.0	47.5
S	1.8	6,800	23.0	47.5
T	16.7	60,000	1.9	145
U	27.0	80,000	1.2	152
V	3.1	13,000	16.0	85

NOTE.—The audio-frequency impedances tabulated in the last column are values corresponding to a frequency of 500 cycles per sec.

12. Grid Bias Supply.

In general terms the theoretical arrangement of grid bias shown in Fig. 1 is impracticable, especially on D.C. mains. With A.C. it is *possible* (provided double-wound transformers are used in each unit so as to provide complete insulation of the output voltages from the supply mains). This necessitates considerable expense which is hardly justified. The arrangement of Fig. 13 is therefore given, where a portion of the voltage drop along the resistance *R* can be used for grid bias. This should be shunted by additional by-pass condensers as shown, while other grid bias voltages may be provided by additional tapping points. The disadvantage of the method is that, since *R* is in series with the common H.T. supply, it provides a certain amount of coupling between the various stages. With too small by-pass condensers there is a serious risk of "howling" on this account. These condensers should preferably be not less than $1\mu F$.

It is also noted by the authors that a very similar arrangement* has been proposed as a means of eliminating the effect of rippie without filter chokes and condensers. The principle is to inject into the grid circuit a

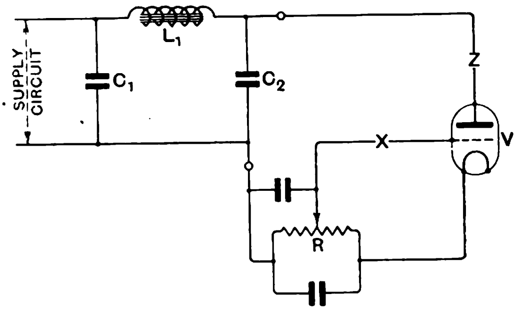


Fig. 13.

proportion of the total available voltage so that the ratio of anode voltage to grid voltage is equal to the amplification of the valve.

13. H.T. Rectifier Arrangements.

It is pointed out that the unilateral conductance of the valve is usually employed as a rectifier to supply the filter of an H.T. supply appliance from A.C. mains. Although an ordinary receiving valve—with grid and anode commoned—may be used, a number of special valves are now marketed for this purpose. They are usually designed to have a copious emission and a low internal

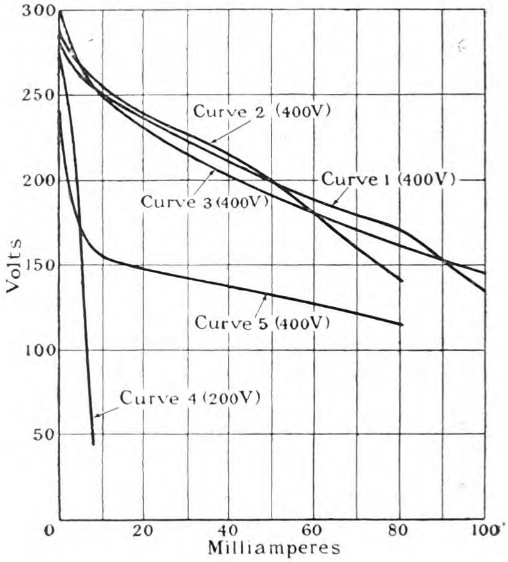


Fig. 15.

resistance, so that they may pass considerable fractions of an ampere without causing an excessive drop in voltage. Typical emission characteristics are shown in Fig. 14 (not reproduced). It is desirable that the total emission should, in general, be not less than 100mA. Output characteristics of several such valves are shown in Fig. 15, curve 5 being for a cold cathode pattern of rectifier.

14. L.T. Supply Appliances.

The use of the supply mains for filament lighting is simple but frequently costly. A simple series resistance to give the requisite drop will still produce disturbances as in the H.T. case unless a filter is used. Such resistance must be in the positive limb or the H.T. supply cannot be taken from the same source. A filter for the larger order of filament currents is expensive on account of the size of chokes and condensers required. Valves of lower filament consumption

* Due to G. M. Wright. British Patent 261110.

simplify the problem chiefly on account of the diminution in the size of chokes. The filaments can be joined in series, but this involves internal rearrangement of the set.

Fig. 16 is given as showing filtering arrangements for filament supply. The floating battery of Fig. 16 (*b*) is probably the most useful filtering arrangement, but still involves battery provision. A single stage of filtration can, of course, be used but with less effective results.

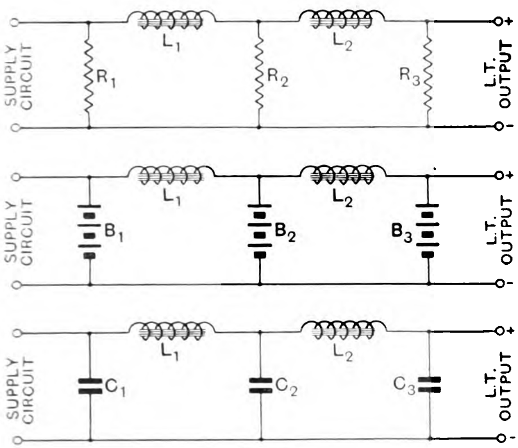


Fig. 16.

15. L.T. Supply Rectifiers.

If the source is A.C. a rectifier must be added as in the case of H.T. supply. The rectifying valves used for H.T. supply are, however, mostly unsuitable for providing sufficient current for L.T. supply. Generally the only available rectifiers are the electrolytic, gas discharge tubes, or solid chemical rectifiers.

It is the authors' opinion, however, that a really effective, efficient and economical type of L.T. supply appliance that can also be correctly described as a true "battery eliminator" has yet to be devised.

The more usually adopted arrangement, particularly for A.C. circuits, is a type of "trickle charger," the battery being automatically charged from the mains at a low rate when the set is not in use. Two batteries may be used combined with an automatic switching device so that one battery is charging while the other is applied to the set.

16. Substitutes for L.T. Supply Appliances.

Reference is here made to the recently developed principle of the independently heated cathode.

17. Miscellaneous Appliances.

The methods referred to here are (*a*) a generator driven from a convenient motive power, or electrically from a low voltage accumulator; (*b*) proposals for the use of voltages generated thermo-electrically from any convenient heat source. It is stated that many proposals have been made in this direction but that the method has not been practically utilised to any appreciable extent.

18. Precautions Necessary in the Use of Radio Supply Appliances.

With the direct electrical connection between H.T. and L.T. at the radio apparatus and in the supply mains, certain precautions must be taken to avoid risk of shock or of dangerous short circuits. A suitable insulated condenser must be inserted in the normal earth connection of the receiver, and properly insulated wire should be used for all connections of the supply appliance and the wireless set. Filter condensers should comply with the B.E.S.A. specification and the earthing condenser should preferably be of the 600 v. class. When the appliances are used on A.C. circuits, the use of double-wound transformers in the rectifiers should protect against short circuits from the mains, provided that the insulation of the transformers is of reasonable quality. If the appliance is metal-cased, the case should be earthed.

During the reading of the paper, demonstrations were given showing the effects of various elements of the filters referred to, especially in Figs. 7 and 10. Alternating voltages were applied to an amplifier and loud speaker, either directly or via the filter under demonstration, and the effects of variation of L_1 and C_2 (of Fig. 2) were shown for various frequencies. The existence of a secondary hump in a two-stage filter (*c.f.*, Fig. 11) was shown, along with its movement on change of the electrical constants. The effect of the input condenser was also demonstrated both without and with rectification.

DISCUSSION.

A lengthy and interesting discussion followed the reading of the paper.

The discussion was opened by **Lt.-Col. H. P. T. Lefroy,** who described a set, with which he had experimented, as an example of mains supply. The L.T. and H.T. were taken through separate chokes, resistances being used for smoothing. He strongly advocated the use of supply mains for convenience and economy.

Mr. W. J. Brown thought the paper went a long way in defining ratings, and discussed the need for knowledge of this. He suggested the third of the authors' proposed ratings as perhaps appealing most to the purchaser. Definition of the smoothing effect was also necessary.

Mr. N. Lea referred to the matter of output impedance. Considerable reaction existed before howling was set up. This was of importance at very low frequencies, especially with R.C. coupling. In rating, it was necessary to state the D.C. " regulation " of each output point, and the output impedance, at some stated frequency.

Mr. Watson discussed instability which might arise from the causes referred to in the paper. This would depend on whether the amplifier represented an overall negative or positive resistance. If it had a negative resistance it would oscillate. This could frequently be reversed by reversing one transformer. In the case of R.C. coupling improvement could be effected by grouping the stages in twos and supplying the groups by separate filters.

Mr. P. K. Turner suggested that the matter of filter could easily be dealt with by known details of the methods of filter design. As regards rating terms he suggested the milliamperes delivered at a stated voltage, and the voltage rise or fall per milliampere.

Mr. J. H. Reyner said that mains supply was now a practicable proposition. The input capacity was important in regulation, especially with single wave rectification. In rating there was also a need for specification as regards hum.

Mr. G. G. Blake thought that the convenience of mains operation would outrun the cost. He also discussed alternative methods of obtaining grid bias.

Mr. Scroggie dealt with the construction and design of choke coils. There was a lack of appreciation of the variation in the inductance of iron-cored chokes with current. He quoted several different cases of the variation with a stalloy core at different currents, and emphasised the need for attention to this.

Mr. Goodall discussed ripple tolerance, and stated that he had found a value of 0.02 volt, which he considered to be more of the order permissible than were the authors' figures. Rating should also indicate the maximum current to be drawn from the appliance.

Mr. P. P. Eckersley emphasised the need for high anode voltages, in the present state of loudspeaker design. He suggested attention to machine generation to work off A.C. or D.C. supply mains and to deliver the requisite H.T., L.T. and grid bias for wireless purposes. This could be made economically and gave scope for regulation and control. For A.C. supply of filament, he recommended a transformer with a potentiometer across the filament so that the grid lead could be joined to the electrical centre.

Mr. Lewis considered that the first condenser was not essential, even in A.C. A first choke was much more important, this practice reducing to a double stage filter without input condenser.

On the motion of the Chairman, **Major B. Binyon, O.B.E.,** the authors were cordially thanked for their paper.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 228 *of April issue.*)

PART II.

1. Geometry and Trigonometry.

SOME of those who have waded patiently through Part I of this series will perhaps be disappointed that the next step will not bring into view the promised land of the calculus; but from the position we have so far reached only a partial view could be obtained. The calculus covers a wide territory. Some of its main lines of communication (to strain the analogy almost to breaking point) pass through regions we have not yet explored—in particular those of geometry and the closely-related subject of trigonometry.

Apart from its bearing on the calculus, geometry, as the study of space and space relationships, has a very close relationship with the problems of theoretical and applied electricity, much closer than might at first be realised. The coils, aerials, condensers, and other apparatus of applied electricity are themselves solid configurations in space, and their functioning is in many cases determined mainly by their "geometry." Also the close analogy that exists between the ideas of pure algebra and those of pure geometry make the latter an indispensable aid in analysis. The graphic representation of functions is an instance of this. The vector diagrams of alternating current theory are another, though in this case the analogy has a very definite physical basis. The representation of a sine wave of E.M.F. as a rotating vector is more than a convenient mathematical fiction. It expresses and symbolises the fact that the E.M.F. has actually or virtually originated in an armature rotating in space with the same effective angular velocity. In fact, the rotating vector can almost be regarded as an end view of the armature.

In view of these and similar considerations a brief account of some of the ideas that originated in the subtle brain of Euclid over two thousand years ago is essential in a course of mathematics intended for wireless amateurs of to-day. For the sake of brevity and compactness the writer is making, perhaps rashly, an attempt to cover the whole of the relevant field of trigonometry and geometry in terms of the vector ideas which have proved of such immense value in their application to specifically electrical problems. It will necessitate beginning at the beginning, but that is probably all to the good as far as most of the readers of this series are concerned.

2. The Straight Line.—Angles.

Geometry has the whole of space for its domain, but two dimensions will suffice for the scope of this series. We shall consider plane relationships only.

The simplest geometrical element is a point, and the next simplest a straight line, which Euclid defined as the shortest distance between two points. In conformity with modern views of geometry, a straight line will be considered as infinite in length unless specifically limited.

A single infinite line in an infinite plane has no describable characteristics except straightness and extension, but each of two such lines in an infinite plane has in addition a direction relative to the other. This relative direction is called the angle between the lines, and is conveniently described by means of letters in either of the ways illustrated in Fig. 1. The angle marked with a star will be called the angle AOB (written $A\hat{O}B$) or θ. Where a single symbol is used (generally a Greek letter) it must be inscribed in the angle as shown.

It is important to realise at the outset that the letter notation of geometry has a dual character In the first place it is used simply to identify certain elements for

reference. In the second, it functions as an algebraic symbol, standing for a number which measures in some specified manner the magnitude of the element. Thus the θ of Fig. 1 serves both to identify the angle $A\hat{O}B$ and to specify its amount, or magnitude. How this amount is to be measured will be considered later.

Apart from any system of measurement, an angle can be thought of as an amount of

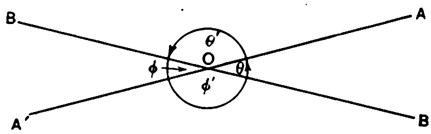


Fig. 1.

turning. Thus the line OB has to be turned through an angle θ about O as pivot in order to give it the same direction as OA. The two alternative directions of rotation (anti-clockwise and clockwise) suggest at once a sign distinction. It is almost universally agreed to consider an anti-clockwise rotation as describing a positive angle (as in Fig. 1) and a clockwise rotation as describing a negative angle. This conforms with the algebraic significance of the negative sign, for

$\theta + (-\theta) = 0$, algebraically and geometrically.

It is obvious that the amount of turning represented by $\theta + \theta'$, *i.e.*, the amount of turning that brings OB into line with OB', BB' being a straight line, is a constant for all such pairs of lines. The angles θ and θ' are called "complementary," each being called the complement of the other. It follows that

$$\theta + \theta' = \theta' + \phi$$

so that

$$\theta = \phi$$

The angles θ and ϕ, θ' and ϕ' are called opposite angles.

If the line OA is rotated about O in a positive direction, θ will increase and θ' decrease, and since the sum of the two is constant a condition will be reached when

$$\theta = \theta' \quad \text{(Fig. 2.)}$$

The line OA is then said to be perpendicular to BB' and the angle θ (or θ') is called a "right angle."

The right angle is the basis of one system of measuring angles. It is divided into 90 equal rotations, each of which is called a degree. (The perverse spirit that seems to preside over the whole English system of weights and measures must surely have had a hand in this awkward choice.) A degree if further sub-divided into 60 minutes and a minute into 60 seconds. In this system a complete rotation is four right angles or 360 degrees, and a half rotation 180 degrees. Thus complementary angles are such that

$$\theta + \theta' = 180^\circ$$

and in practice the definition is extended so as to include the case in which either angle is greater than 180°, the other being correspondingly negative.

Later on another system for the measurement of angles will be described. This alternative system, though numerically not much more convenient than the degree system, has a less arbitrary basis. It cannot be fully explained, however, until we have some understanding of the great principle of geometrical similarity on which it is based.

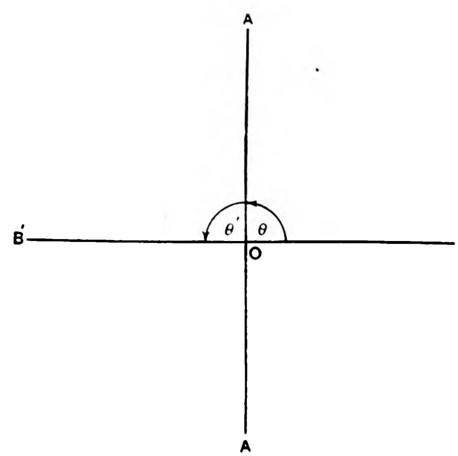


Fig. 2.

3. The Triangle.

Suppose now that a third line is introduced into our infinite plane (see Fig. 3). Each of the three lines will then acquire the additional characteristic of relative position as well as relative direction. (This is not

immediately relevant, but is introduced to emphasise the essentially relative character of position, and the fact that two other lines are required to specify it.

The figure bounded by these three co-planar straight lines is called a plane triangle. The sides can be described by means of the letter pairs AB, BC, CA, or more conveniently by the single letters shown in the figure.

Notice first that if the line $A'C'$ is turned about A through the angle α in the direction shown, then about B through the angle β and then about C through the angle γ, it will make a half revolution, the points A' and C' reversing their position with respect to B. Therefore

$$\alpha + \beta + \gamma = 180°.$$

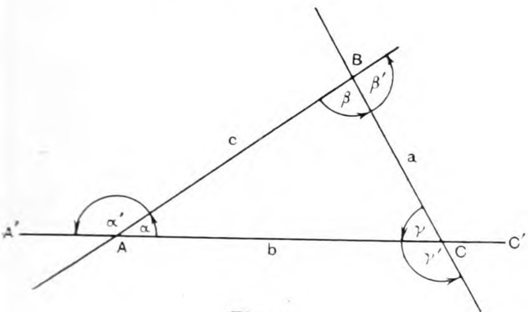


Fig. 3.

In words, the sum of the internal angles of a triangle is two right angles. Further, since

$$\gamma' + \gamma = 180°,$$
$$\gamma' = \alpha + \beta$$

and similarly for the other pairs of internal angles. The angles α', β' and γ' are called the external angles of the triangle.

Only one metric property of the sides can be stated so far. It follows from the definition of a straight line that

$$a + b > c \quad b + c > a \quad c + a > b,$$

i.e., any two sides of a triangle are greater than the third.

4. Parallels.

Suppose the line BC (Fig. 3) is rotated in a positive direction about B. The point C will move along $A'C'$, as shown in Fig. 4, and the angle γ will decrease continuously. As γ decreases the sides a and b will increase continuously. The relationship

$$\alpha + \beta + \gamma = 180°$$

will however remain true throughout. As

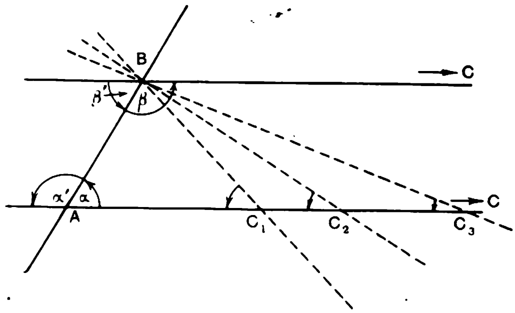


Fig. 4.

the rotation continues it is clear that a condition will be reached when

$$\alpha + \beta = 180°$$

and in consequence

$$\gamma = 0$$

In this condition the line BC is said to be parallel to AC. It will be shown later that a and b are then greater than any finite quantity however large, *i.e.*, the point C is at infinity. Since

$$\alpha + \beta = 180° \text{ and } \beta' + \beta = 0$$

it follows that

$$\beta' = \beta$$

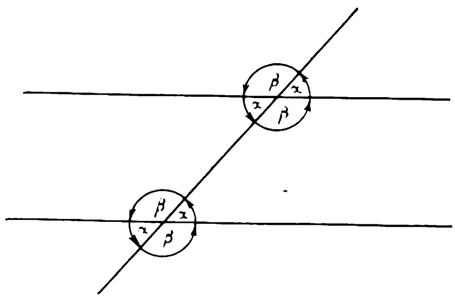


Fig. 5.

These are obviously general relationships, true for any pair of parallel lines and a third cutting through them both The angular equalities are as indicated in Fig. 5.

5. Equality of Triangles.

By the complete equality of geometrical figures is meant the equality in magnitude of all the corresponding elements, sides, angles, etc. A practical criterion of equality is that the one figure, placed on top of the other, will coincide with it at every point.

The two triangles ABC and DEF of Fig. 6 are equal in every respect if

$$\begin{array}{lcl} AB = DE & & A\hat{B}C = D\hat{E}F \\ BC = EF & \text{and} & B\hat{C}A = E\hat{F}D \\ CA = FD & & C\hat{A}B = F\hat{D}E \end{array}$$

but obviously not all these conditions are necessary. For instance, if two pairs of angles are given equal, the remaining pair must also be equal (see Sect. 3). What are

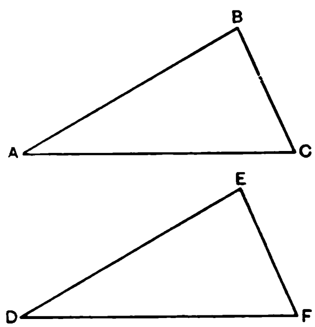


Fig. 6.

the minimum conditions that will ensure complete equality? There are three separate combinations of such conditions.

(a) Two sides and the included angle, *i.e.*,

$$AB = DE$$
$$AC = EF$$
and
$$A\hat{B}C = D\hat{E}F$$

(b) One side and the angles not opposite to this side, *i.e.*,

$$AC = DF$$
$$C\hat{A}B = F\hat{D}E$$
and
$$B\hat{C}A = E\hat{F}D$$

(c) Three sides, *i.e.*,

$$AB = DE$$
$$BC = EF$$
$$CA = FD$$

The first two are very easily proved by considering the second triangle to be, as it were, lifted and placed down on the first. The proofs are too simple to justify giving space to them. The third cannot be proved in this way, and will be deferred till later.

6. Geometrical Similarity.

The above discussion of equality brings us to one of the most practically useful and important ideas in the whole of geometry,

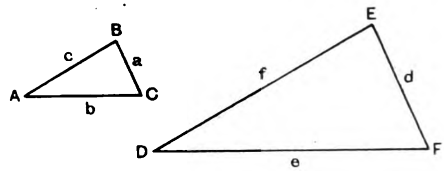


Fig. 7.

the idea of geometrical similarity. It is probably not generally realised that the whole science of trigonometry, with its applications to surveying, navigation and astronomy, is based on this one principle. The idea is concerned with the relation between equi-angular triangles, *i.e.*, triangles of which the corresponding angles are equal. Such triangles are not necessarily equal in every respect, as Fig. 7 will show. There is, however, a definite metrical relation between such triangles, the relation being

$$\frac{a}{d} = \frac{b}{e} = \frac{c}{f}$$

The proof is not easy, but an outline of it will be given on account of its importance in all that follows.

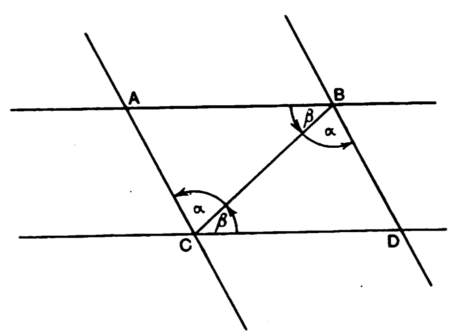


Fig. 8.

Consider first the diagram of Fig. 8, in which AB is parallel to CD and AC to BD. It follows from the properties of parallels that the angles marked with the

same Greek letter are equal. The triangles ABC and DBC, having the side BC in common and these angles equal, are equal in every respect, by the preceding. Therefore

$$AB=CD \quad \text{and} \quad AC=BD$$

This is the first step. Now look at Fig. 9, where B is the middle point of AC, BD parallel to CE and DF parallel to AC. By applying the result just proved it is easy to show that $AD=DE$. This result can be extended as shown in Fig. 10. If the line AB is divided into n equal parts by the parallels to BC, then AC will a'so be divided into n equal parts or "segments." Returning now to Fig. 7, the smaller of the two triangles can be drawn inside

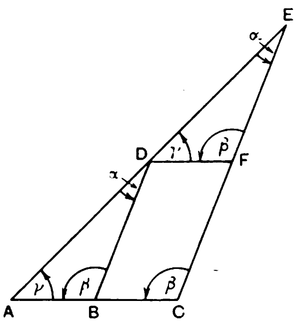


Fig. 9.

the other, as shown in Fig 11, the line BC being parallel to EF, in virtue of the angular equalities assumed. If the ratio of AC to AF is expressed in its lowest terms as the fraction m/n, AF can be divided into n equal segments by lines parallel to, and including, BC. The line AC will be divided into n equal segments by n of these lines. It follows from the preceding that AB and AE will be similarly divided by these parallels, so that

$$\frac{AB}{AE}=\frac{m}{n}=\frac{AC}{AF}$$

Similarly by withdrawing the smaller triangle so that B coincides with E, it could be shown that

$$\frac{AB}{AE}=\frac{BC}{EF}=\frac{CA}{FA}=\frac{m}{n}$$

i.e.,

$$\frac{a}{d}=\frac{b}{e}=\frac{c}{f}$$

It follows from the properties of fractions proved in Part I of the series, that

$$\frac{a}{b}=\frac{d}{e} \quad \text{and} \quad \frac{b}{c}=\frac{e}{f}$$

both of which equalities are included in the form

$$a:b:c=d:e:f$$

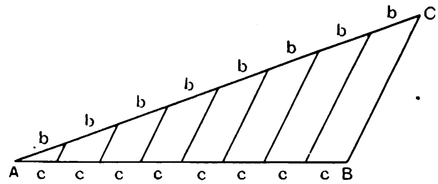


Fig. 10.

This means that the *relative* magnitudes of the sides of a triangle depend only on the shape of the triangle, and will be the same for all triangles having two angles of the one equal to the two corresponding angles of the other. That is the important conclusion to remember. Two triangles related in this way are said to be similar. The trigonometrical ratios which will now be described are no more than an expression of this similarity in the particular case of right-angled triangles.

7. The Trigonometrical Ratios.

Consider the right-angled triangle shown in Fig. 12. Any other right-angled triangle containing the angle of θ will be of the same

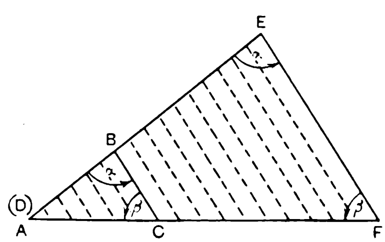


Fig. 11.

shape as this. Therefore the relative magnitude of the sides, *i.e.*, a/b, c/b and a/c, and the reciprocals of these ratios or numbers, will depend only on θ. They can therefore be considered as functions of θ and tabulated

for various values of θ. Special names, tabulated below, are given to these numbers.

Apart from the reciprocal relationship,

Ratio.	*Name.*	*Abbreviations.*
height/hypothenuse	sine	sin
base/hypothenuse	cosine	cos
height/base	tangent	tan
hypothenuse/height	cosecant	cosec
hypothenuse/base	secant	sec
base/height	cotangent	cot

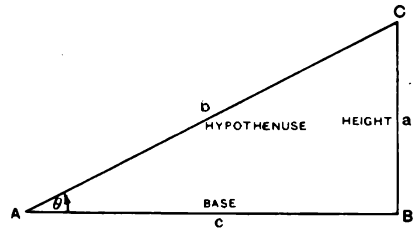


Fig. 12.

it is clear that these ratios, being functions of θ, must also be functions of one another, and will therefore possess certain inter-relationships. One is immediately obvious from their definition, for

$$\frac{sin}{cos}=\frac{\text{height}}{\text{hypothenuse}}\Big/\frac{\text{base}}{\text{hypothenuse}}=\frac{\text{height}}{\text{base}}=tan$$

Another important relationship will be proved later.

In practice the above definitions of the trigonometrical ratios are extended, as shown in Fig. 13, to cover any value of θ up to four right angles. The positive angle θ is the amount of anti-clockwise rotation of AC from AX, and $sin\ \theta$ is BC/AC, etc., etc. Similarly for the remaining quadrants.

Without further qualifications, however, an angle such as θ', where $AB=AB'$ and $BC=B'C'$ in magnitude, would have the same ratios as θ. The ambiguity is avoided by a sign convention relating to the constituent lines of the ratios. The sloping line is considered to have no sign at all but all other lines are considered to be measured away from the centre A, and are taken as positive in the directions AX and AY and negative in the directions AX' and AY'. Thus (Fig. 14), if the lines have the magnitudes shown by the small letters, BC and ED are interpreted as the number a, BG and EF as the number $-a$, and so on. This convention results in the following signs for the ratios in the various quadrants :—

sin	+	+
cos	—	+
tan	—	+
sin	—	—
cos	—	+
tan	+	—

The table need not be memorised, as it is easier to apply the sign convention direct in any given case.

Remembering that a negative angle is a rotation in a clockwise direction, it is easy to see that

$$sin\ \theta = -sin\ (-\theta)$$

$$cos\ \theta = \quad cos\ (-\theta)$$

and therefore

$$tan\ \theta = -tan\ (-\theta).$$

Further, there will be certain simple relationships between the ratios of angles that differ by positive or negative multiples of a right angle. For instance,

$$sin\ \theta = \quad cos\ (90^\circ - \theta)$$
$$cos\ \theta = \quad sin\ (90^\circ - \theta)$$
$$sin\ \theta = -cos\ (90^\circ + \theta) \text{ etc., etc.}$$

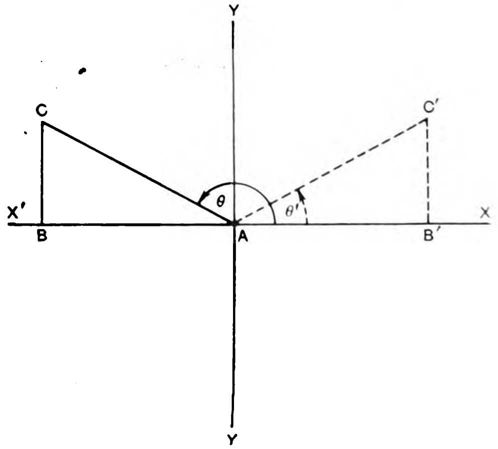


Fig. 13.

These, again, need not be memorised, as it is much easier to draw the appropriate lines in a quadrant diagram in any given case.

Given that

$$sin\ \theta = n$$

θ may be described as the angle having the sine n. This is written, conventionally

$$\theta = \sin^{-1} n.$$

It should be noticed that whereas $\sin \theta$ is a single-valued function of θ, *i.e.*, given θ there is only one value for its sine, $\sin^{-1} n$ on the other hand is many valued, has in fact an infinity of values, for if θ be the smallest angle having the given sine, $\theta + r \times 360°$, r being any integer, will all have the same sine. Similarly for the other " inverse " functions.

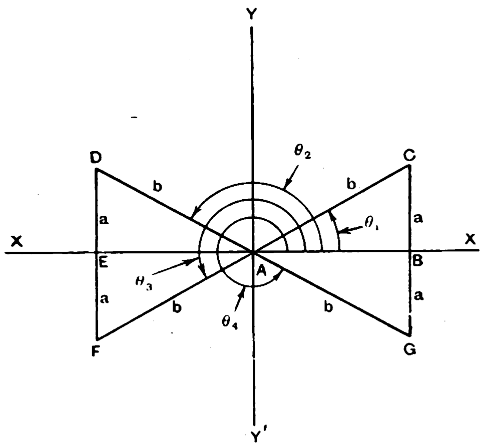


Fig. 14.

There is no need to illustrate the sine and cosine of an angle graphically, for these curves will already be familiar to all students of electricity in connection with wave forms of alternating currents. Before leaving this part of the subject, however, some important special cases should be noted. Referring to Fig. 12,

$$\sin \theta = a/b \qquad \cos \theta = c/b$$

Now as θ tends to zero, b tends to equality with c and a tends to zero, so that

$$\sin 0 = 0 \qquad \cos 0 = 1 \qquad \tan 0 = 0$$

Similarly

$$\sin 90° = 1 \qquad \cos 90° = 0 \qquad \tan 90° = \infty$$

$$\sin 180° = 0 \qquad \cos 180° = -1 \qquad \tan 180° = 0$$

etc., etc.

Examples.—May, 1927.

1. Two angles of a triangle are 17° and 83°. What is the third angle ?

2. An irregular pentagon is a five-sided figure with equal sides. Prove that the sum of the internal angles is 540°. (Join the corners of the pentagon to a point inside it.)

3. The sides a, b, and c of the triangle in Fig. 7 are 4, 5, and 9 ins. long respectively. The side f of the triangle DEF is 10 ins. What are e and d ?

4. Show that :—

$$\operatorname{cosec} \theta \tan \theta = \sec \theta$$
$$\sec \theta \cot \theta = \operatorname{cosec} \theta$$

5. Given that $\sin 50° = .766$, and that $\cos 50° = .643$, find the values of : $\tan 50°$, $\sec 50°$, $\operatorname{cosec} 50°$, $\cot 50°$, $\sin 140°$, $\cos 220°$, $\tan 320°$, $\tan -50°$, $\sin 40°$, $\sec -40°$.

6. Find the value of $(\sin 50°)^2 + (\cos 50°)^2$.

Answers to Examples in March Issue.

1. (*a*) $1 - x + x^2 - x^3 + x^4$

   (*b*) $a^{-1} + \frac{1}{5} x^5 a^{-6} + \frac{3}{25} x^{10} a^{-11} + \frac{11}{125} x^{15} a^{-16} + \frac{44}{625} x^{20} a^{-21}$

   (*c*) $1 + 3x + 6x^2 + 10x^3 + 15x^4$

2. This depends on the fact that

$$n(n+1)(n+2) \ldots . (2n-2) = (2n-2)(2n-3) \ldots . n.$$

3. 2.9931.

4. 1.9520.

7. Prove by expansion of ϵ^{-1} and grouping of the terms in pairs.

Design and Construction of a Superheterodyne Receiver.

By P. K. Turner, A.M.I.E.E.

IN setting out to write a description of some experiences in building supersonic sets, I should like to emphasise the fact that this is simply a " description." It does not pretend to be an authoritative or didactic article. Frankly, I feel that my experience of this type of set is not sufficient for that purpose, while at the same time the results may be of interest. Secondly, I should like to make it clear that the views expressed herein, and the designs suggested, express my own ideas only, and not necessarily the views of the organisation with which I am connected.

When I first considered the prospect of investigating this type of set, I had in mind one very clear-cut idea, which was supported by the admirable article by Armstrong in the Journal of the I.R.E., of October, 1924, that in most supersonics there were too many valves eating their filaments off in semi-idleness. I had always insisted in other sets that my valves should earn their nourishment very fully, and I wanted to find out whether they could not be made to do so in a supersonic.

The layout of a typical supersonic receiver would comprise eight valves: an oscillator, two detectors, three I.F.s (intermediate frequency) amplifiers, and two L.F. amplifiers. Of these, only five are actually amplifying.

Before one can go into the possibility of economy, it will be as well to investigate shortly the work to be done by each type, if only to clear up our ideas.

The Oscillator.

The first duty of this is, obviously, to maintain quite steady oscillations which can be added to those coming in from the distant station. The frequency is determined by the necessity of producing beats of a definite " intermediate frequency " to which the intermediate amplifier is tuned.

The proper amplitude of the steady oscillation is a more difficult matter. We are, of course, dealing with typical heterodyne reception. It is known that if the steady local oscillation is *less* powerful than the incoming wave, the strength of the resulting beat is more or less proportional to the local oscillation. Obviously then, we will keep the local current at least equal to the incoming. It has commonly been said that if the local oscillation is greater than the incoming one, the resulting beat is proportional to the latter. But Appleton and Taylor, in the Journal of the I.R.E. of June, 1924, and Colebrook in *E.W. & W.E.*, of May, 1925, have shown that owing to the peculiarities of detectors the matter is more complicated than this, and that the resulting beat is a maximum for any given incoming signal if the local oscillation bears a certain definite (but variable) proportion to it, of the order of five to twenty times as strong. The matter is further complicated by the fact that a variation of strength of the local oscillation, if done by adjustment of the oscillating valve itself, and not merely by adjusting its coupling to the detector, may alter the proportion of harmonics generated by it. This is a most important matter, as will be seen later, when the matter of harmonics is discussed more fully.

The First Detector.

Here we meet with one of the two great difficulties of the supersonic—or any other set. That is, from the point of view of one writing about them. For the rectifier, whether valve or crystal, is undoubtedly quite difficult to investigate, though it is easy enough to write about in a popular (and probably inaccurate) manner.

Let us clearly understand, to begin with, why the first detector is needed. One often hears it rather casually stated that " the mixture of currents at two different frequencies produces beats of a frequency equal to their difference and that the beats are amplified," or some such statement. Now,

firstly, such a mixture does not produce beats of the difference frequency, and secondly, one cannot amplify a beat. The correct way to state the case is to say that " the sum of two equal currents of differing frequencies is equivalent to a current of the average frequency, modulated at a frequency of *half* the difference." Although it is modulated, it is still a high frequency current, and cannot be amplified by an amplifier tuned to the difference frequency.

But if it is rectified, the case is different. Here again, there seem to be some confused ideas. It is not quite correct to assume that if one puts in a pure alternating current to a rectifier one gets a simple direct current out of it. Just exactly what one gets out depends on the rectifier; but with a simple alternating input of frequency f, one will almost certainly find the output to be a mixture of: a direct current, an alternating current of frequency f (that of the input), one of frequency $2f$, and probably others of frequency $3f$, $4f$ . . . etc. If, however, the input is fully modulated, for the same maximum amplitude the output will contain a smaller D.C. than before, the difference being made up by a current of twice the modulation frequency, and others of four times, etc., this.

Now suppose that the input to our detector consists of a local current of frequency f_0 (o for oscillator) and a distant current of frequency f_d, then this is equivalent to (*a*) a current of f_0, because the original f_0 current is stronger than the f_d one; (*b*) a current of frequency $f_0+f_d/2$, modulated at the frequency $f_0—f_d/2$.

The output from the detector will then contain

(1) from (*a*) and (*b*) a direct current;

(2) from (*a*), currents of f_0, $2f_0$, etc.;

(3) from (*b*), a current of frequency twice $f_0—f_d/2$, and others of 4, 6, 8 . . . times this frequency;

(4) from (*b*), a current of frequency $f_0+f_d/2$, and others of 2, 3 . . . times this.

There may be others, and some of these may be small, but the above is typical of the "mixed bag" flowing in the output circuit.

If then f_0 and f_d are two fairly high "radio" frequencies close together—say 1,000 and 900kC, we shall have the following:—

(1)	from (*a*) and (*b*) ..	D.C.
(2)	from (*a*)	1,000,000 2,000,000 3,000,000, etc.
(3)	from (*b*)	100,000* 200,000, etc.
(4)	from (*b*)	950,000 1,900,000, etc.

If we tune the output circuit to 100,000 cycles, and couple it to an amplifier which is also tuned to this frequency, we can pick out that component (marked with a * above); and this is what is done.

It is to be noted that if the local current (*a*) is stronger than the distant one (*b*), all those components derived from (*b*) will be proportional to (*b*).

Our 100kC output is among these; and if (*b*) was modulated at audio-frequency, this component will faithfully reproduce the modulation.

The essential point to remember is that the detector output is by no means one of a simple difference-frequency, but is a complex current containing a whole series of frequencies. The D.C. and the "high" frequencies (2) and (4) will not get much further consideration, though they may cause trouble by "beating" among themselves. But the series of harmonics (3) of "intermediate" frequency must be looked into.

It is true that they do not interfere with the final result, for they are stopped by the amplifier, which is tuned to one frequency only. But it must be remembered that the object of the supersonic is to "reduce" all incoming signals to the same intermediate frequency, by varying the local oscillations. Thus in the case above, a signal of frequency 1,000kC would be welcomed by a local current of 900 or 1,100kC. The rectifier output will contain (among others) a component of 100kC, as required. But suppose one were using 900kC as local frequency, and another signal of 950kC came along. Then there would be in the output a frequency of 50kC which would be duly stopped by the tuning. But there will also be the harmonics of 50kC, and the second harmonic is 100kC, so our 1,000kC signal will be jammed, if the second harmonic is strong enough.

Further, if the local oscillator is set to 950 or 1,050kC, there will again be 50kC and its harmonics in the output, and the second harmonic will be amplified. Nor is this the only trouble, for the local oscillator itself almost certainly sets up harmonics, which in the course of searching for one station may set up beats with another. Later on, in describing my first efforts at a set, I will give an actual example of what may occur. For the present, enough has been said to show that harmonics in the local oscillator, or set up in the process of detection, may cause much confusion if they are at all strong, and should therefore be avoided.

Obviously then, the most important points in the first detector are (*a*) there should be comparatively few harmonics set up by it; (*b*) it should be reasonably sensitive to small input.

The Intermediate Amplifier.

The duty of this is—in theory at least—a simple one. It is to select from among the various currents flowing in the circuit of the first detector one definite one, and amplify it. Unfortunately, in the case of a supersonic set for broadcast reception, we are confronted with the fact that we have to amplify, not a single wave, but a band; while there are such possibilities of extreme selectivity that we are tempted to try to separate stations very close together; we are asked therefore to give a large and even amplification to a certain band of frequencies, while "cutting out" all others.

It may be of interest to explain here in a few words just *why* the supersonic is so essentially selective. It is due to the fact that a *difference* of frequency appears unchanged after the first detector, and is a larger percentage of the small intermediate frequency than of the large original frequency; and selectivity depends on percentage differences.

Thus, take a 300-metre signal modulated at 1,000 cycles. This acts as if it were a mixture of three currents, at 999,000 cycles, 1,000,000 cycles and 1,001,000 cycles respectively. If we set to beat with it a current of 900,000 cycles, we shall have in the output (among others) currents of 99,000, 100,000 and 101,000 cycles. Thus the modulation is preserved unchanged. Now suppose an interfering station on 297 metres. This is 1 per cent. away from the first, and is hard to tune out. But 297 metres is 1,010,000 frequency: our beating current of 900,000 cycles will set up in the detector output a current of 110,000, which is not 1 per cent. off but 10 per cent. off that which we are trying to get. In fact, the separation (in percentage) of the two stations is multiplied by the ratio of the intermediate to the incoming frequency.

The action of the supersonic principle itself, then, is to multiply the separation between stations. To take advantage of this, we must still have a selective intermediate amplifier. But if it is one fraction too selective, it will begin to cut off the higher notes which form the extreme edges of the band of wanted signals. Thus, taking the case mentioned above—300 metres—but modulated at 5,000 frequency and "converted" to 100,000 cycles by the first detector, we find that the amplifier should

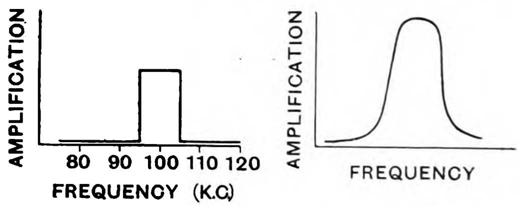


Fig 1. Fig. 2.

On the left, the ideal resonance curve; right, the type obtained in practice.

have the same overall performance for all frequencies between 95,000 and 105,000, but should not work outside these limits. We want a resonance curve like Fig. 1. Actually, such a curve cannot be got; all resonance curves are more or less of the type of Fig. 2. But it is an interesting point that by employing several stages of amplification, each one fairly selective, a much more "flat-topped" curve can be got than by putting up one very selective stage. This idea was rather fully developed by the present writer in *E.W. & W.E.* of October, 1925. Later, we will take up the actual design of the amplifier to get the required selectivity.

As to the actual frequency to be chosen for the intermediate amplifier, there are conflicting requirements which lead to a compromise. In order to get maximum selectivity, the frequency should be low; but this is not very important; for the total selectivity is limited, as just pointed out; the limit can

easily be reached with an intermediate frequency of 100,000. The frequency must, however, be considerably lower than (say one-third of) the lowest frequency to be received, which means not more than 50,000 if Daventry is to be received.

If, however, the frequency is *too* low, there are increasing difficulties due to the I.F. being too near the modulation frequencies. Practically, 30,000 (10,000 metres) is getting near the limit.

The Second Detector.

Although the main function of both detectors is to rectify, the properties required of the first and the second are widely different in detail. For example, the second detector

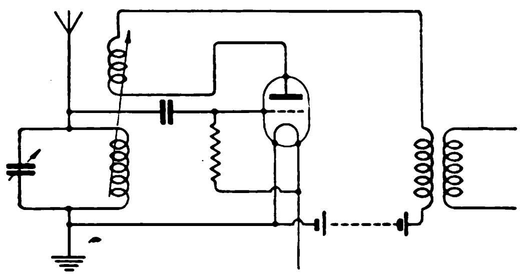


Fig. 3. *This simple circuit is not successful for a supersonic oscillator, as it is too far from being tuned to the incoming wave.*

is seldom required to work on very small input, while the first is. Again, harmonics (beyond the second) set up in the first rectification have to be tuned out in the amplifier, and are a nuisance; but harmonics in the second are actually heard as distortion, and must be avoided at all costs. In general, the second detector works much as does the one detector of an ordinary set; but the fact that it has a long-wave input (3,000 to 10,000 metres) may have its effect on our choice of type.

The L.F. Amplifier.

Here we are on familiar ground—but even here we may find in details that the fact that the input to our detector is of lowish frequency may have to be considered.

Possible Economies.

Now, having considered the duties of the various parts of the set, we must consider how valves can be saved. The possibilities are fairly obvious. One or both of the detectors may be crystals; if the first detector is a valve it may be made to act as oscillator also; the H.F. valves—if any—may be made to do duty as I.F. also; some of the I.F. valves may be made L.F. also.

A crystal as first detector was tried by the writer in the first attempt ever made at supersonic work, and was fairly successful. But it was given up because it involved the use of a separate oscillating valve, and it was found more efficient and little more difficult to make the oscillating valve detect as well.

The use of a combined H.F. and I.F. valve is a feature of the Radiola set. In order to avoid the necessity of an extra tuning control, a "semi-aperiodic" transformer is used. Personally, I do not favour the idea. *Pace* Captain Round (who, I know, holds the opposite view) I do not think that an H.F. amplifying valve is a necessity in a supersonic. Since this type of set is above all one for simplicity of handling, it seems a pity to introduce another tuning adjustment, and a more or less untuned H.F. coupling does not appeal to me, even if the stage can be got by a valve that is doing I.F. work as well. Incidentally, a fair experience of reflex working leads me to suspect that it will be none too easy to get stable *and* efficient combined H.F. and I.F. amplification.

When, however, we come to reflexing I.F. to L.F. valves, the matter is rather more favourable. Firstly, it is certain that there will be I.F. and L.F. amplification in the set. Secondly, one has no variable tuning to face. The matter is not quite so simple as reflexing high frequency valves to audio-frequency, as I.F. and L.F., being nearer to one another, are not so easy to separate. But in practice I have found it quite successful.

A First Attempt.

After a certain amount of thought on these lines, and a few preliminary experiments with a one-valve "frequency converter" put in front of an existing long-wave reflex amplifier, I proceeded to design the first set.

One point was found quite definite in these first experiments: that any attempt to reflex the first I.F. valve and make it do L.F. work as well was likely to produce instability.

No definite reason could be stated, but the general conclusion was that it was due to the fact that the input circuit of this valve already contained such a mixture of frequencies from the detector that the addition of audio-frequencies upset its digestion. I do not propose to describe this set in detail, for its good points were used in the later set, but it will be, I think, advantageous to show its bad points, as a lesson in what to avoid. Shortly, it was a four-valve set: combined detector and oscillator on the second harmonic principle; 3 I.F.s; crystal second detector; and two of the I.F.s also as L.F.s.

The first troubles that turned up were due to the harmonic oscillator. For the sake of completeness I must outline the action of this. If, as in Fig. 3, we try to make the first valve oscillate and detect in the usual way, we lose efficiency because the aerial circuit must be tuned to the oscillator frequency and not the incoming frequency, and these are not quite close together as in ordinary heterodyne reception.

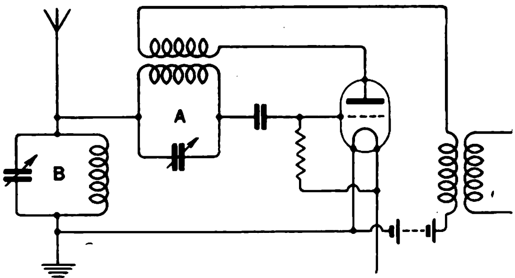


Fig. 4. *An alternative to Fig. 3. Its disadvantage is interference between circuits A and B, which is avoided by tuning A to half its normal frequency.*

It was soon suggested that one should use, as in Fig. 4, an additional circuit *A* tuned to the oscillator wavelength, keeping the aerial tuned to the incoming frequency. But although the two frequencies are too far apart for efficient use of the circuit of Fig. 3, they are near enough to one another for the rejector action of the circuits *A* and *B* to be felt; each tends to choke the other and the slightest change in either alters the circuit conditions for the other.

It was Huth's suggestion that the circuit *A* should be tuned to *half* the required frequency. Thus, say we want to beat at 900kC against a 300-metre signal in *B*, instead of tuning *A* to 333 metres we tune it to 666. The oscillating valve, as usual, has its output harmonic currents, and the second harmonic is of the required frequency of 900kC (333 metres).

In practice there was one serious disadvantage. I could not get a valve to generate *only* the fundamental and second harmonic—it invariably set up a whole series. When I first tuned the set over the broadcast band (at about two miles from 2LO), London kept on coming in. It was not flat-tuned; in fact it was dead sharp at each position; but there were 11 positions at which it could be got.

How this occurred is as follows: First, the deliberate encouragement of the second oscillator harmonic (by using extra bias on the grid) caused the third—and others—also to be strong. Second, these conditions also caused extra harmonics *of the I.F.* to be set up in the process of rectification. Third, the second harmonic of 2LO itself was quite strong at that range. I worked out in detail what might have been expected, as a table. I give here a similar table for the case of a 300-metre incoming signal and 100kC I.F., which gives simpler numbers. To show the idea, take the first case. If the oscillator is set at 300kC, meaning to use its second harmonic (600kC) to beat against 500kC or 600 metres coming in, its third harmonic sets up 100kC beats with our 300-metre station.

If it is set to 950 metres, the third harmonic sets up 50kC beats; but since extra harmonics are set up in rectification, the second of them is 100kC, and gets through the I.F.

In Table I, the first two columns give wavelength and frequency of the oscillator. The two "proper" positions are starred. The third shows which harmonic of the oscillator is effective for that setting; the fourth shows whether it is the fundamental or the second harmonic of the incoming signal that is concerned; the fifth shows the frequency of the resulting beat, and the sixth gives what harmonic of this (generated in rectification) is audible.

After some experience of this it was definitely decided that in any future sets, steps would be taken to keep harmonics down to an absolute minimum!

Another trouble which arose was due to the fact that the last audio-frequency valve

like the others, was an I.F. valve as well. This was puzzling at first. The symptom was instability whenever the output was brought up to full loud-speaker strength, which at once suggested overloading of the valve by the combined I.F. and L.F. input. This was tested out by putting in an extra big valve, with such voltages as to make sure that there was no overloading in the ordinary sense of the word. The trouble was still there.

TABLE I.

Oscillator. λ m	Oscillator. kC	Oscillator Harmonic.	Incoming Harmonic.	Difference kC.	Harmonic Heard.
1,000	300	3	F	100	F
950	317	3	F	50	2
930	322	3	F	33	3
870	344	3	F	33	3
850	350	3	F	50	2
815	367	3	F	100	F
670*	450	2	F	100	F
630	475	2	F	50	2
620	483	2	F	33	3
580	516	2	F	33	3
570	525	2	F	50	2
545*	550	2	F	100	F
475	633	3	2	100	F
460	650	3	2	50	2
455	656	3	2	33	3
442	678	3	2	33	3
435	684	3	2	50	2
430	700	3	2	100	F
333	900	F	F	100	F
317	950	{ F	F	50	2
		2	2	100	F
	967	F	F	33	3
	975	2	2	50	2
	983	2	2	33	3

and six others above 1,000kC.

Next it was thought that it might be due to slight curvature of the first reflex valve characteristic throughout, which may cause a sort of super-modulation, as I have explained at length in "The Perfect Set" (*E.W. & W.E.*, October, 1924, – August, 1925). This was tested out by putting a picked valve in the first position, which did not cure it.

Eventually it was concluded that when the output of the last reflexed valve was very large, and its arrangement was that of Fig. 5, as in this case, there would be enough audio-frequency voltage across *L* to cause an appreciable component to appear in the throw-back transformer besides that due to the rectification of the I.F. In this case, of course, there is audio-frequency reaction, and a howl will be set up. Accordingly, it was definitely decided that in future sets the last valve should be a pure L.F. power valve.

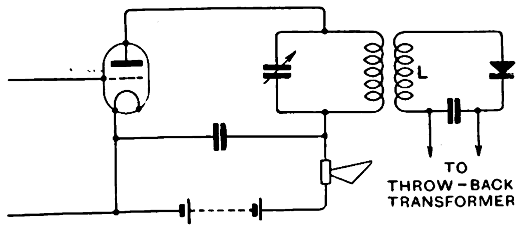


Fig. 5. *When reflexing an output valve, we find trouble due to the L.F. voltage across* L.

The third trouble found was a general "trickiness" due to stray capacities and couplings. It was seen that careful consideration must be given to layout.

The Second Set.

On the basis of the experience gained a considerable time was devoted to the detail design of the second set. It was decided straight away that this should comprise five valves: a "detoss" or combined oscillator and detector; 3 I.F.s; crystal second detector; two of the I.F.s to be used for L.F. also; and a final power valve.

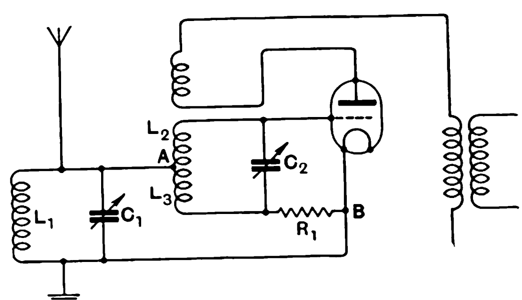


Fig. 6. *A well-known bridge "detoss" circuit which is not really satisfactory.*

Since the harmonic "detoss" system had shown such serious disadvantages, some alternative had to be found, and some sort of bridge circuit seemed to be indicated. At the time when this was being settled there was a popular circuit known as the

"Tropodyne," which is shown in Fig. 6 (of course, a frame can replace the open aerial and aerial tuning coil). The theory of this can perhaps be better seen from Fig. 7. It

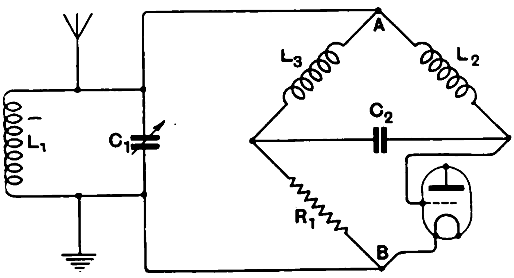


Fig. 7. *The circuit of Fig. 6 redrawn, to show why it cannot be balanced accurately.*

will be seen that incoming signals set up a voltage across L_1C_1, which is passed to the valve *via* L_2; L_3 and R_1 are in shunt, and cause a slight loss of energy which is not

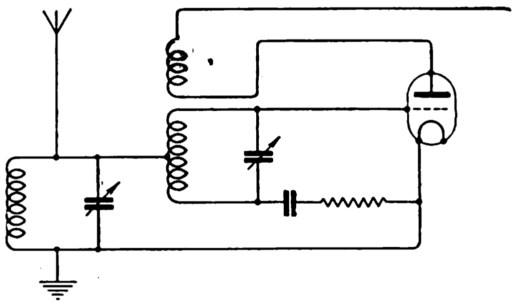


Fig. 8. *This gives some improvement over Fig. 6, but it is still impossible to maintain the balance.*

important. On the other hand, if $L_2=L_3$ and R_1=the input impedance of the valve, these four form a balanced bridge; at any frequency of the oscillator the potentials at A and B are identical, and although voltages are induced into L_2 and L_3 by the reaction coil, thus causing oscillation in the circuit $L_2L_3C_2$, none of this gets back to the aerial. The oscillation frequency is controlled by C_2, and the aerial tuned to the incoming signal by C_1.

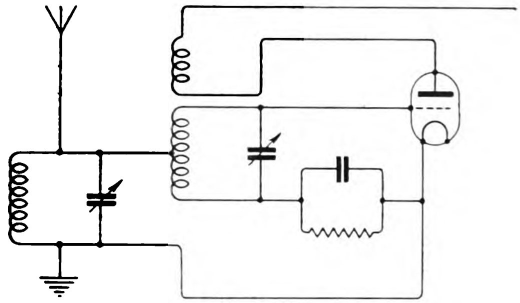


Fig. 9. *A possible modification to Fig. 8, subject to the same criticism.*

Unfortunately, however, this simple circuit is far from perfect, for in practice the bridge cannot be balanced. The input impedance of the valve is of the nature of a capacity and resistance in series, and such a combination cannot ever be balanced by a pure resistance. It can be balanced by a capacity and resistance in series, or by a different capacity and resistance in parallel, so that one might hope to get better results by the circuits of Figs. 8 and 9. But there is still a serious difficulty. The input impedance of the valve is not a constant thing. It varies with the filament, grid, and anode voltages, with the setting of the reaction coil, and even perhaps with the strength of incoming signals. Hence the balancing capacity and resistance can only represent a mean value; and the bridge may often be unbalanced.

(*To be continued.*)

The Solar Eclipse and its Effect on Radio.

Some Suggestions for Research During This Year's Total Eclipse of the Sun.

A Lecture before the Radio Society of Great Britain by Captain H. de A. DONISTHORPE, delivered at the Institution of Electrical Engineers, on Wednesday, 23rd March, 1927.

IT gives me the greatest pleasure to be before you once again this evening after an absence of some three years in the U.S.A., but it is with some sorrow that I note the apparent falling off in interest by the radio amateurs of this country in their science, a fact which, for some unknown reason, seems to have been brought about by the advent of broadcasting here.

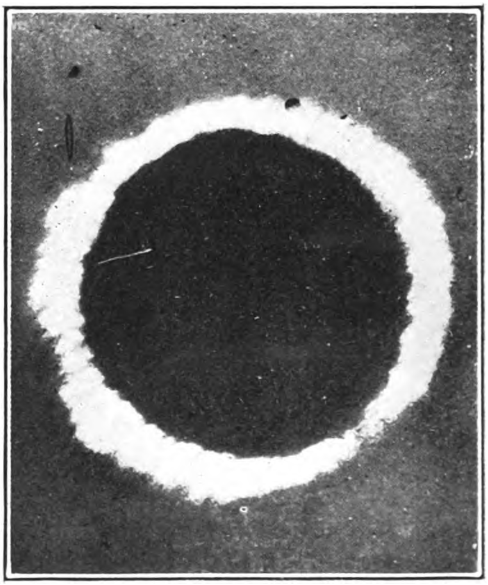
In America there has been no falling off in the numbers of radio "fans," who still find much to maintain their interest in radio matters.

Looking back at my records I find that it is about four years since I read a paper before you, and on that occasion I spoke on one of the latest developments then—namely, the four-electrode valve. Since that time radio has made great strides in all parts of the world.

After a careful study of the conditions in America as compared with ours I have come to the conclusion that we have little to learn about radio from the other side of the Atlantic, although I will say their broadcasting is more entertaining than that to be found here. Broadcasting over there, on the other hand, as I have stated before, has had no effect on the activities of the radio experimenter, who is still as zealous as ever over his work.

A few weeks ago I attended an informal meeting of this Society, when it was deplored that there was little to-day for the amateur to do in the line of research. I, however, disagree with that statement. At that meeting that very able and enthusiastic follower of our activities, Captain Ian Fraser, also seemed to be of the same opinion and considered that there was little left for us to experiment upon, bar the perfecting of each of our individual receivers, or the hunting for far distant broadcasting stations. It is my intention, therefore, this evening to put before you some points which outline a very definite line of research for all radio amateurs to follow during the coming June.

During 24th January, 1925, it was my good fortune to witness in New York City one of the marvels of the universe, namely, a total solar eclipse.



The sun during total eclipse showing the corona.

We here are to see such a phenomenon this year providing we are able to take a day's holiday and travel to the Midlands, and I can assure you that it will be a journey worth while, always of course providing the climate conditions are favourable.

In the New York eclipse conditions were ideal and precisely at 9 a.m. a part of the

city was plunged in complete darkness after a prolonged twilight period.

One of the interesting visible points about the eclipse was its definition. As you know, the streets of New York are divided into parallel blocks and numbered, and whilst in the 'nineties only a semi-eclipse was noticeable from 110th Street onwards to another definite street totality was witnessed.

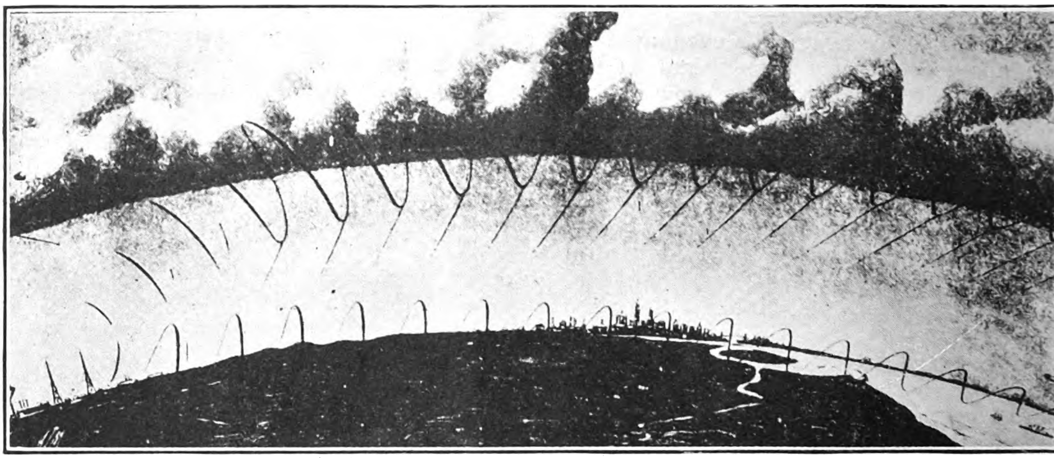
It was the wish of many that the city should not be supplied with artificial light at the critical time, but the New York police knew better of their underworld to allow this, and the general public were therefore disappointed by the presence of full night lighting throughout the eclipse.

At the precise moment of totality those in the track of totality witnessed the unusual sight of all the stars suddenly coming out like a second night, together with the wonderful sun's corona.

You will no doubt by this time be inquiring what all this has to do with radio reception or the propagation of electro-magnetic waves.

It is no doubt presumptious on my part to mention the effects known as "night effects" to a body of radio enthusiasts, but that is the connection between radio and a solar eclipse. This "peak" reception, as you all know, has always been a phenomenon that has been studied by all radio engineers and experimenters, and it is therefore my intention to detail some of the effects that we noticed in America as far as radio is concerned during their total eclipse, with a view to suggesting a line of research for all the members of this Society.

Positively speaking, we all know that the sun's rays have a very definite effect on radio waves, and we also know that this effect is closely associated with that mysterious phenomenon called the "Heaviside layer." Perhaps for the purpose of clearness it is desirable at this stage of my paper to briefly refresh our memories as to the theory of the "Heaviside layer" seeing that this phenomenon is so clearly connected with the *raison d'être* of my talk.



By courtesy of the Scientific American

The ground path and the upper reflected path of the wave.

Radio engineers of to-day consider that there are two wave paths possible for the waves emitted from a transmitter, one the ground path and the other the upper wave path. During the night time the upper path is subjected to alterations due to a variation of the ionisation of that upper layer. These variations cause the direct path of the wave alternately to reinforce or oppose the direct path of the wave. Now it is during the night or darkness period that the ionisation occurs which causes an alteration in the speed of this indirect wave. This alteration, however, is not uniform, and consequently the progress of the wave is disturbed in a most complicated manner.

Darkness is caused by the eclipse; it is therefore reasonable to associate this phenomenon with the night effects associated with radio, especially having due regard to the

fact that the darkness period does not occur in its usual diurnal frequency.

Before I actually discuss the details of the American tests I want to make it quite clear that this talk is not intended to be a complete work on the subject—in fact, that would be impossible due to the short time I have had available to prepare it—but rather as a general outline with the object of acting as a guide to our experimenters along which they may direct their efforts.

By courtesy of the Scientific American

The total eclipse in America, 24th January, 1925.

Luck as usual favoured America during the eclipse and the scientists were not hampered by bad atmospherical conditions, visibility was excellent as far as the optical observers were concerned, and the atmosphere was free from static for the radio experiments.

Dealing only with the radio side of the question, it can be said there were some variations and contradictions as far as the results are concerned, which were due possibly to purely local disturbances or accidental faults of local receivers.

Ignoring these isolated cases and taking an average of the results obtained, it was found—and I want you to take careful notice of these—that the results differed according to the position of the transmitter and receiver relative to the track of totality.

The experiments were conducted with the aid of certain broadcasting stations and these transmitted on waves which by previous experience gave the greatest night effect and were confined to continuous wave transmission. It was also arranged as far as possible for the receivers to be spaced from the transmitters at distances where maximum fading had been noticed. These receiving sets were tested for five days prior to the eclipse in order to note whether they were consistent in their readings.

I do not propose to go into the details of the receivers which actually were modified superheterodynes coupled to strength recording apparatus. A further opportunity will be available to discuss this apparatus at one of the later informal meetings of this Society. It will be of interest, however, to learn that in some cases it was quite possible for the human ear to detect the variations of the signals received from the special stations.

During the brief interval of totality of a solar eclipse, it will be interesting to note that the sun's rays are cut off from an area of several thousand square miles whilst for

several hours there is semi-darkness over a considerably larger part of the earth's daylight surface.

In summarising the results noticed I cannot do better than quote Mr. Pickard, of the

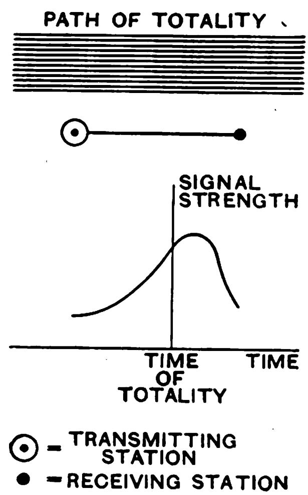


Fig. 1.

American Wireless Speciality Apparatus. He says: "For those wavelengths and distances, which are better at night than day, the eclipse improved reception; whilst the wavelengths and distances which are nor-

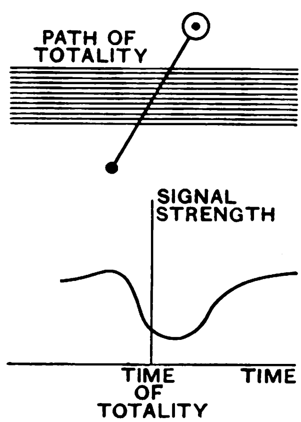


Fig. 2.

mally better by day than night the eclipse decreased reception."

The results, as I have mentioned before, differ with the relative positions of the transmitter and receiver, and these I will now detail.

Case I.

When the listener and the transmitter were on the *same* side of the shadow there was a gradual *increase* in the signal strength beginning about twenty minutes before totality and falling off again by about ten minutes after totality. (Fig. 1.)

Case II.

When listener and transmitter were on *opposite* sides of the shadow there was a *decrease* beginning a few minutes before totality and lasting until after totality. (Fig. 2.)

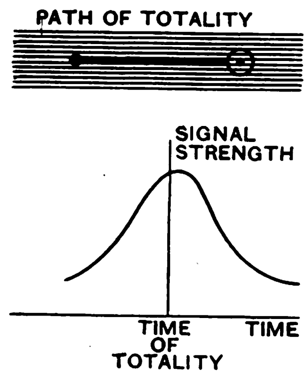


Fig. 3.

Case III.

When both listener and transmitter were *within* the shadow there was a relatively sharp increase in signal strength practically coincident with totality at the transmitting station. This fell off rather quickly after totality was over. (Fig. 3.)

Case IV.

When the *listener* was *in* the shadow and the transmitter *outside* there was a falling off shortly before totality with an increase after totality, falling away again afterwards. (Fig. 4.)

The eclipse occurred at a time in the morning when the sun's rays had not entirely done their work on the ionised layer, as otherwise greater variations would have probably been noticed.

As far as our eclipse is concerned, which takes place on 29th June, it occurs at an

unfortunately early hour, namely 5.23 a.m., which is difficult from a domestic point of view as well as at a time when the sun's rays will barely have made their presence felt on the ionised layer.

The track of totality extends from the North of Wales, Carnarvon to Hartlepool. The B.B.C. have very kindly consented to get their engineers up early that morning and special signals will be sent from Daventry and other stations the particulars of which will be disclosed later. The Radio Corporation of America has also kindly consented to co-operate and to arrange to send some special signals from their stations and they now only wait to hear from me as to our details when they will make the necessary arrangements. We ourselves can

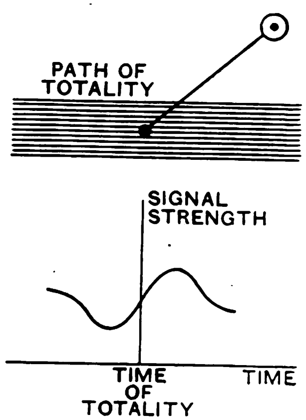


Fig. 4

enlist the services of the T. and R. members to send some special signals for listeners on their short wave stations.

I venture to suggest in conclusion that it is necessary for our Society to organise itself so that we can collect in a comprehensive manner all the data obtainable and make the necessary arrangements for listeners and transmitters within and without the path of totality.

I therefore suggest that a committee be formed for this purpose. I understand that our Mr. Cooper is to attend a conference of the Department of Scientific and Industrial Research in connection with this forthcoming eclipse, and it will be interesting to hear later the results of this conference. If there is anyone here this evening who is connected with that Board, it would be pleasing if he will say a few words afterwards as to their suggested programme.

My talk this evening was originally intended for the informal meeting of 22nd April, and I therefore suggest to the Chairman that since that date is now vacant it might be useful to use it for a general discussion on this subject and for the formation and issuing of instructions for our research, providing, of course, it is decided that the Society is going to participate in the work of elucidating the effects of this eclipse on radio. I offer these latter suggestions for your consideration.

DISCUSSION.

Admiral Sir Henry Jackson : We are very much indebted to Captain Donisthorpe for his very interesting lecture, and it is very opportune, as it takes time to prepare and organise any observational work that is going to be done during the eclipse. He mentions that we had a conference at the Department of Scientific and Industrial Research with a number of persons interested, not only our own staff, but others representing the commercial wireless companies in the country and the B.B.C. We have not got out all our details yet, but they will be published, so I will leave that matter for the moment. The results of the New York eclipse are very interesting indeed, and, so far as I can see, they quite uphold the theory which is accepted about the effect of the ionised layer. When the moon is between the sun and the earth, the sun's radiation and corpuscles cannot reach it, and this tends to raise the height of this ionised layer for a time. That would make a great difference, especially to these amazing skip distances on short waves. The T. & R. Section will deal with that, and it will be really useful if they will organise a good series of observations. There is one point which Captain Donisthorpe did not mention and which I had never looked into until a few days ago. It is that the visible shadow of the moon on the earth is over a different place from that of the shadow of the Heaviside layer. In the case of the eclipse this year, if we imagine that the Heaviside layer will be about 60 miles up at the time of the eclipse, then the path of the eclipse on this layer in Great Britain will be above a track from the Bristol Channel to the Wash, instead of from North Wales to Hartlepool. Consequently, we are selecting the disposition of our receiving sets to meet this point, that is farther to the south than we should have done if the two paths had been the same. This is a point worth remembering ; there is not the slightest doubt about it, and I think the effect is more likely to be noticed on that southern path than it would if the northern path is taken. In order to be on the safe side, we are arranging for fairly long signal distances and are going well each side of the paths. Mr. Cooper attended a meeting of the T. & R. Section and said he would try to organise a few signals. In fact, he is suggesting a transmission from Iceland, and, I think, from

Caterham. I do not know whether the owners of the transmitters will be able to agree to it, but we shall then be well on both sides of the lines, whichever line is taken. A point to be remembered is that if a large number take part in it they must choose their wavelengths so that there will not be interference and jamming between each other. Another point we settled was that we should have time signals, and I think the B.B.C. are arranging to give time signals from all the stations which will be working that morning, every quarter of an hour. I think this ought to be good enough for those taking an active part in the above observations, if they get the Greenwich time signal—six dots—every quarter of an hour. We are going to try to have long waves, short waves and broadcasting waves, and the results on the various wavelengths recorded. Some very good results have been obtained recently with regard to the height of the Heaviside layer. The height can be calculated very accurately from the fringes which are photographed, and we hope to be able to get two sets of photographs from two different stations across the band. I think Captain Donisthorpe has given us something to think about, and I hope that advantage will be taken of what he has said.

The President: We have present to-night Mr. Hope Jones, the expert on time signals, who has already written to me on this subject, making certain suggestions as to some of the steps the Society might take. I hope he will say something now.

Mr. Hope Jones: The programme of time signals which the B.B.C. will be asked to transmit on the morning of 29th June is by no means fixed yet. The Royal Astronomical Society, representing the astronomers generally, have not yet prepared their formal request, which the B.B.C. have been good enough to indicate will be favourably considered. Admiral Sir Henry Jackson has mentioned that the six dots will be transmitted at 6 o'clock and at 6.15, and doubtless they will also be transmitted at 6.30 (Summer Time), but it is quite on the cards whether there will not be a much more elaborate programme of time signals during the actual period of totality. That is the one thing that astronomers can time; they cannot time the first contact, but they can time the beginning and the end of totality with exactness, and it has been suggested that for the three minutes from 6.22 to 6.25 we might have a continuous series of seconds dots, which would mean 180 of them. That is obviously open to one objection, that you will be confused with the counting unless you have an announcer—I think our B.B.C. announcers are capable of anything—a man who, without risk of mistake, calls out in staccato tones "5," "10," "15," and so on, with every five dots, and it may be that something of that kind will be seriously proposed. I think the question for this meeting (and for the adjourned meeting which Captain Donisthorpe has suggested should be held on 22nd April), is whether such time signals really will be useful as a means of making observations on signal strengths. I am not at all sure that these dot-seconds, of very short duration, are good for the purpose. The special time signals will doubtless be transmitted from 2LO and from Daventry, and also perhaps, if desired, from Liverpool, the Leeds-Bradford Station, and from Newcastle.

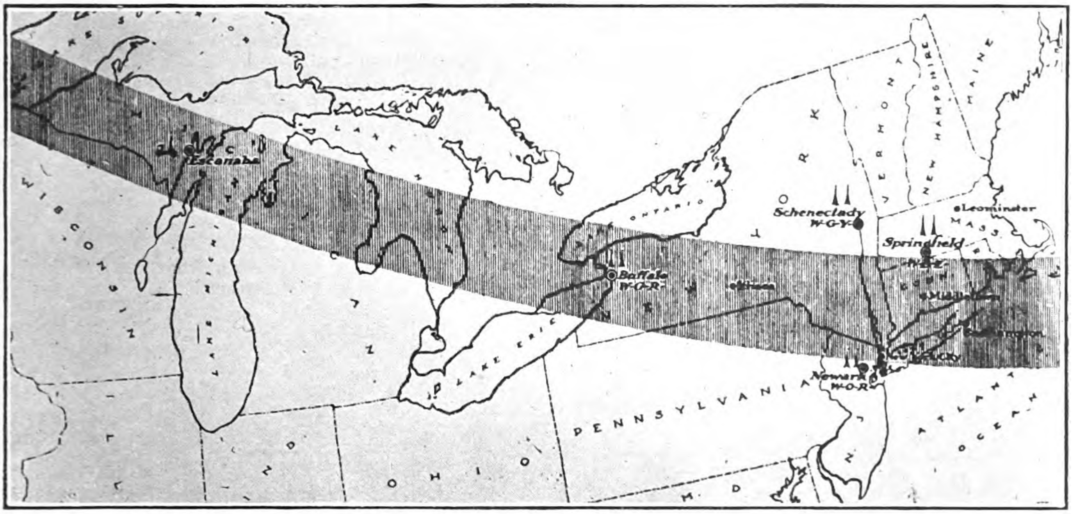
Mr. Bevan Swift: Captain Donisthorpe has enabled us to visualise what might occur during the eclipse. Looking at it from the amateur rather than the professional point of view, we can imagine the Heaviside layer in a very distorted form with quite a big bump on it, a condition which, of course, is normally never reached under the sun's rays, because the raising of the Heaviside layer at day time is a much more even occurrence, whereas during an eclipse, when the sun's rays are confined to a comparatively small portion of the ether, a very unusual effect must be produced. From the short wave point of view, we all know the difference between 45 and 23 metres. On 45 metres we get wonderful, though, it must be admitted, not consistent, effects at night time, whereas 22.5 or 23 metres is an effective wavelength for transmission in the day time. How is the solar eclipse going to affect that peculiar phenomenon? There must be a mean between the two, obviously, when we must get something of each. Therefore, we must be able to obtain some result such as that, which will be of tremendous value in judging the fading effect, and it would be of interest to arrange our tests partly on 45 metres and partly on 23 metres, so that we could see if there were any material appreciation on the one wavelength and any material diminution on the other. With regard to the question of skip distances on short waves, we all know that some stations are infinitely bad to receive from, that is, they do not happen to come in the tangent of the angle of reflection which is commonly supposed to exist. Whether that angle will be altered by the peculiar distortion of the Heaviside layer it is hard to say, and this is a point which our tests might very well be arranged to investigate. There is only one other point I want to raise, and that is with regard to Mr. Hope Jones' excellent suggestion as to seconds dots, and his reference to the difficulty of counting them. I would remind him of the old method adopted at the Eiffel Tower, of leaving out every tenth dot.

Mr. Maurice Child: With regard to these short wave tests, whilst, of course, they should be carried out, it is also important for us to bear in mind, as Sir Henry Jackson has already indicated, that for more or less localised observations round about the British Isles we want to use rather longer wavelengths as well. It would appear that, by working over the British Isles with such short wavelengths as those mentioned by Mr. Bevan Swift, we should not be likely to get very good results. The skip distances could come in, and we should not be likely to get contact. I do not mean that we should not use them, but I am suggesting that we should also get some very valuable data by using intermediate waves of, say, 70 metres and 100 metres, and even 125 metres, and so on. I think we should ask the Postmaster General to allot several wavelengths on that particular morning. Although Captain Donisthorpe rather deplored the fact that this eclipse takes place at such an early hour, I think really we can be very thankful that it is to take place at that time, because the B.C.L. people, who would otherwise interfere with the scientific work, will be in bed. I cannot conceive of anything

more unfortunate for the scientific aspect of the thing than to get all the B.C.L.'s interested in it. They will heterodyne each other, and the influence on these particular wavelengths on which they know from experience they can get their local stations would be simply terrible, I should think. Mr. Hope Jones made rather a useful suggestion with regard to time signals, and, if it is of any interest, I would suggest the possibility of doing the sort of thing I did two or three years ago when I was listening for atmospherics periodically in connection with the organised tests for which Dr. Eccles made himself responsible. The method is to mark a number of dots down in a line on a piece of paper, with a space between each, and to tick off each dot with a pencil as you hear it, so that you do not have to worry about the number. It is quite easily done. You simply mark the number of dots on paper corresponding to those transmitted and tick each one off as you hear it, and also make a little mark against any particular dot if at that point you hear anything phenomenal in the way of atmospherics or any other signal variation. Then, by counting the dots afterwards, the exact time at which a particular phenomenon occurred can be determined. Alternatively, I would suggest the method mentioned by Mr. Bevan Swift, namely, of leaving out the dot at each period of ten seconds. There is still another method, however, and that is to superimpose a note of slightly different pitch on to the one already being sent, say, at every ten or twenty seconds. If, however, you prepare a sheet of paper beforehand with the dots marked on it, it will not be necessary to send out a special signal at all; I did not find any difficulty with that method.

Mr. Hope Jones: If I may be allowed to speak again with regard to time signals, I would point out that it would be a little difficult, with the existing apparatus at the Observatory, to arrange a system by which the dot could be left out at every tenth second, or some such interval as that. The omissions would have to be effected by hand. I need hardly say that whatever time signals are sent out have to be absolutely correct, to 1/100th of a second. With regard to Mr. Child's remarks as to the facility with which the dots can be counted, if you have them marked on paper and follow them with a pencil, I might say that the person to whom the time signals are sent is primarily the astronomer in the field. He is busy with his telescope, spectroscope and other things, and he rather looks forward to hearing an audible signal whilst his mind, his eyes and his fingers are engaged in other work.

The President: I should like to ask Captain Donisthorpe one or two questions. In the first place, I should like to ask what wavelengths were employed in America at the time of the eclipse? I should also like some information as to the nature of the signals sent out. I take it that the mere recording of the signals themselves is only half the work; the strength of the signals requires also to be recorded if we are to have complete information. I have not heard it stated this evening, but I take it that some Department, perhaps the National Physical Laboratory, is taking steps to do all that, and what the members of the Society should do, and should do in order to assist the investigation and to justify the existence of the R.S.G.B. as a scientific body, is to get as much information as can be afforded them, and as much direction as they can, as to what they should do in order to get the most useful information and the best results. Captain Donisthorpe made a very useful suggestion, that on 22nd April, when the paper he has read to-night was intended originally to have been read, a discussion should be opened



Path of the total eclipse, 24th January, 1925, showing the distribution of the stations which participated in the tests.

in connection with this whole matter, so that everybody in the Society who is interested in it may hear a little more about what the conditions are, and in what way they can best help to get all the information, in tabulated form, that is necessary for working out the results after the event. He has also suggested that a small Committee should be set up by the R.S.G.B. to look into the matter, but I hope we shall have both the Committee and the discussion, because I think that probably the discussion will be of more use than the Committee; very often discussions are more useful than Committees. At any rate, I am sure that any of our members who can assist and cooperate with the people who are officially carrying out the experiments will render great service. I am not clear what is going to be done with regard to members of this Society or others sending out signals on their own account, but I am quite clear that if not regulated in some way it will confuse matters very considerably. I will now ask Captain Donisthorpe to reply.

Captain H. de A. Donisthorpe, replying to the discussion, said: Referring first of all to Admiral Sir Henry Jackson's remarks—the point about the relative positions of the two different paths, the one of totality and the other of the Heaviside layer—I have not heard of this before, but I think it is a most interesting point. I do not remember it being referred to in America during the experiments there. There is just one point I should like to mention to Mr. Hope Jones in connection with the remarks he made, which might interest him. One of the tests was carried out with telephony, and there was a stenographer taking down the signals at the transmitting station, and another at the receiving station. There were very accurate clocks both at the transmitting and the receiving stations, and as a certain word was transmitted, the time was taken at both stations to see whether there was any difference. If the wavelengths referred to by Mr. Bevan Swift, *i.e.*, 23 and 45 metres, are used, I think there will probably be some interesting results which will be characteristically different. I will repeat the words used by Mr. Pickard to suggest my remark, namely, "For those wavelengths and distances which are better at night than day, the eclipse improved reception, whilst for the wavelengths and distances which are normally better by day than night the eclipse decreased reception." Concerning our President's questions, the signals were sent out on the usual broadcasting bands; 491 and 379 were the wavelengths of the two broadcasting stations, and there was one long wave station sending out at 3,500. In some instances the signals were sent out on telephony, and the others were tone modulation.

Mr. Maurice Child: There is one little thing that a lot of us could quite easily do on the morning of the eclipse. If we are very lucky we may get something on our receivers, and it would be very interesting to know if there is any variation in the intensity of atmospherics during the eclipse. It is well known that on the Mediterranean at daylight there are atmospheric disturbances, and they might possibly be repeated in this part of the world. At any rate, it would do no harm to make a few observations in that direction.

Captain H. de A. Donisthorpe: In one particular instance at the period of totality, certain atmospherics of a rather strong nature were observed by a ship at sea, which blotted out signals, but about five minutes afterwards they disappeared. I do not know if that was the only instance recorded.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

That Audio-Transformer Problem.

To the Editor, E.W. & W.E.

SIR,—Mr. I. A. J. Duff has, in his letter in your February issue, made a number of comments on this problem, which, in my view of the matter, are open to considerable correction or criticism.

Since all theory results from practical experiment in the first instance, it has always seemed to me that an admission of a difference is an admission of incomplete knowledge or visualisation of the subject in question. In the present subject, the fundamental principles of which *are* so exactly known, can we not banish such differences ?

I think Mr. Duff will eventually see that his statements to which I took exception, and which he repeats as " still true " and " theoretically true " but modified in practice, are not intrinsically true at all—he will see that higher ratio transformers (lower primary inductance) can, as referred to by Mr. E. Green (October issue) with advantage be used with lower impedance valves because the impedance may still be equal to that of the valve at the nearly lowest note required and the amplification on all notes greater, and not because " inter-capacities and leakages come in and upset one's theory."

In my original letter, I ought perhaps to have stated more clearly in the early stages that the principle of equality refers to comparison at one given frequency, as I see that Mr. Duff in his fifth paragraph is following Mr. Hall in making comparisons of a nature beyond the scope of that principle as I intended to convey it.

Remembering that frequency is a physical quantity of a very fundamental nature, let us clearly distinguish between the two divisions of the audio-transformer problem, viz. :—

(*a*) Effects at any one given frequency due to variations of other quantities ;

(*b*) Variation of these effects when the frequency is varied in certain defined circumstances as regards other quantities.

In regard to both it should be noted that because an amplification figure at a high frequency is greater than the optimum figure for a low frequency, it does not follow that it is even approximately the optimum figure at that high frequency.

There was no intended reference to (*b*) in my original letter, except in my last paragraph. It is a big subject which has already received duly large attention in various published articles.

In regard to (*a*) the question at issue is this :—

Concerning variation of transformer windings, do we, with a valve and transformer combination, get maximum overall volt-amplification at the given frequency when the effective impedance of the primary is the utmost possible, or do we get it in some other circumstances, *e.g.*, in those of approximate equality of that impedance with that (the anode A.C. resistance) of the valve ?

Mr. Albert Hall, supporting the original statement of Mr. Duff, says that we get the maximum when that impedance is of the utmost possible value. I cannot understand why they should hold this view, because the ampere-turn effect of a winding in series with a fixed resistance on a given overall P.D., which winding is made progressively finer and finer, ultimately decreases. That which takes place in the anode impedance of a correctly biased valve is, within reasonable valve limits, accurately represented by considering a pure resistance of amount equal to the impedance or anode A.C. resistance of the valve to be placed in series with that anode impedance and an overall P.D. of amount μ times the P.D. applied to the grid to act upon the combination.

It would seem that Messrs. Duff and Hall are not cognisant of the principle of a fixed and variable impedance in series on a given P.D. by which maximum activity (volt-amperes) occurs in the variable impedance when it is *equal* to the fixed, a result which is only slightly modified by the presence of hysteresis, eddy current and parallel capacity effects or by the fact that the resistance of the variable winding is not in exact proportion to its inductance. In this connection may I, Sir, particularly emphasise that the condition of equality of variable impedance with that of fixed impedance for maximum power (watts) in the variable impedance is only a *particular case*. In passing I would like to remark that a realisation of this fact under the correct conditions would perhaps clear up the difficulty between Messrs. E. Green and Holt-Smith. The necessary condition in all cases is that the power factors or phase angles of the variable winding and of the combined impedance remain substantially constant, or what is the same thing, the winding resistance, except when relatively unimportant, remains reasonably proportional to the inductance, and the parallel capacity, when present, also varies to suit. The principle admits of a very neat diagrammatic proof.

What, therefore, is, as twice admitted by Mr. Duff, true of the output transformer, is also true of the stage transformer, the variation in the former case occurring by loading up the transformer and in the latter by varying the winding fineness, the inductance being approximately proportional to the square of the number of turns. Valves with similar constants are required for the two cases, but with considerably less capacity (possible grid potential swing) in the stage case.

Mr. Duff accuses me of a " colossal howler " as a result, I fear, of an imperfect grasp of some of the basic principles with which we are concerned and of not clearly appreciating the postulated basis of variation of the quantities involved, in particular

the fact that variable valve conditions are not in question. He himself makes the error of interchanging the fixed and variable impedances and still thinking of the effect in the now fixed impedance. Naturally the effect in the *fixed* is greatest when the variable is of zero impedance. Also, when he changes the valve, is its impedance the only thing he alters? And can he show a case of increasing the *power* output by so doing as he would have to be able to do to be consistent?

My original qualifications concerning the variation of R and X were sufficient to render Mr. Duff's comments thereon unnecessary, but in any case it makes very little difference if R is widely disproportional to X because R is always small in relation to the total resistance or reactance.

Because variable valve conditions are not in question the ρ parts of Mr. Duff's 1 and 2 are of no import. If in 2 he means $X^2 + R^2$ to vary he makes the error of ignoring the effect of this on σ the transformer ratio.

In what sense is it correct to say that "a nice topped curve" is gained "by picking a σ to suit the valve"?

Mr. Duff says that Mr. Holt Smith gave a different angle to the discussion. How does he explain Mr. Holt Smith's instance of increased amplification when the winding fineness is reduced?

It is not correct for Mr. Duff to say that "one big firm" agrees with him—he has only had the personal support of Mr. Albert Hall. I feel that he has re-entered this discussion emboldened by the support he has received into saying some things perhaps without full self-conviction.

Finally, Sir, may I say that to describe my part in this discussion as "rushing into the fray" is far from the truth. A large amount of thought has been given to the matter, and though certain points are open to reasoned criticism, which I whole-heartedly invite, and in which connection it will be remembered that statements cannot always, for space reasons, be made *exactly* correct I do not think I am guilty of any "colossal howler."

E. Fowler Clark,
Derby. B.Sc., B.A., A.M.I.E.E.

Sir,—From the remarks of Mr. E. Fowler Clark, B.Sc., B.A., A.M.I.E.E., in your March issue regarding the above matter, he would appear to have mixed up the requirements necessary in a good high frequency transformer-coupled amplifier, with the quite different requirements of a good low frequency amplifier.

In the case of H.F. transformer coupling, the maximum amplification is provided when the valve and transformer primary impedances are equal, owing to the fact that the energy in the transformer primary is then a maximum, and consequently there is the maximum transfer of energy from the primary to the secondary windings, these being, of course, quite elementary considerations. The case of the low frequency amplifier is fundamentally different, in that one does not require to amplify one particular frequency enormously, but to amplify all audible frequencies to as nearly as possible the same extent.

It should be very easy to see that when a transformer primary is connected in series with a valve, one has two impedances in series, and the alternating impulses provided by the valve are impressed across these impedances in proportion to their relative values and phase. From this it follows that if the two impedances are at any particular frequency equal to one another, the proportion of the amplified voltage applied to the primary of the transformer is equal to $\sqrt{0.5}=.707$ of the valve amplification factor.

If the transformer impedance at any particular frequency is made infinitely great with respect to that of the valve, almost the whole of the amplified voltage produced by the valve is applied across the transformer primary terminals.

All transformers have resonance peaks where their impedance is to all intents and purposes infinite, and consequently, at such peaks, the whole of the amplification factor of the valve with which they are used is made use of.

If the impedance of a transformer can, by any means, be made very great at all other audible frequencies, it is very obvious that the voltage across the transformer primary will not vary appreciably.

From the foregoing, it follows immediately that the ideal condition is to obtain the highest possible impedance at all frequencies, and since it is comparatively easy to get a high impedance at, say, 2,000 cycles, even in a poor transformer, it is essential for the inductance of a transformer and its corresponding impedances to be as great as they possibly can be at the lowest audible frequencies. So that, even though the impedance does increase above those frequencies, the amplification does not increase.

The secondary winding merely steps up the voltage applied across the primary, and whilst capacity effects may be, and frequently are, present, which cut off the higher notes to a great extent (owing to the effective impedance of the transformer primary being reduced), this deficiency can be allowed for in the design of a good transformer, such as the one obviously referred to in Mr. Fowler Clark's insinuation regarding certain recent advertisements.

It is interesting to observe that transformers built on the assumption that the primary impedance is as high as possible at the lowest audible frequencies, actually do give far superior results to these in which this fundamental consideration is not followed.

Failsworth. J. Baggs.

H.T. and L.T. from a 250 Volt D.C. Supply.

To the Editor, E.W. & W.E.

Sir,—A few points arise out of the paper by A. Robertson (*E.W. & W.E.*, p. 111, February, 1927) which might be constructively criticised from the practical point of view.

The writer has at present over 300 installations at work off the mains on all sorts of receivers in over 30 towns.

The criterion of silence is in these cases the commercial one of complaints and their elimination.

It is not often that one has the advantage of a double circuit tuner when fitting in mains units but for obtaining absolute silence a double circuit

is more efficient than any combination of two condensers and choke. There are, of course, simpler arrangements of double circuits which are just as efficient as that shown in Fig. 1 (as regards silence) but with the advantage of requiring only one tuning adjustment.

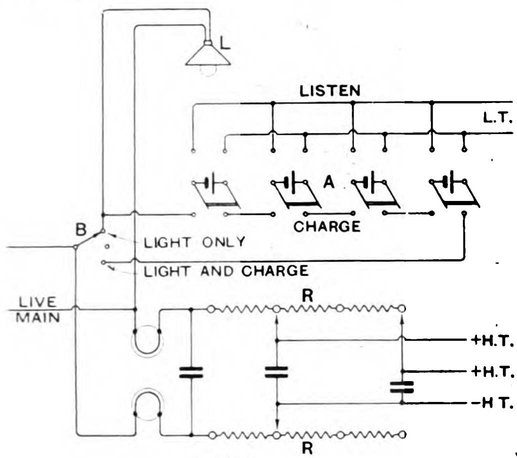


Fig. 1.

A. 4 *D.P.D.T. switches with* 1 *D.T.G. cell across each pair of centre terminals.*
B. *Room switch with* 1 *"off" and* 2 *"on" positions.*
R. *Tapped non-metallic resistances.*
L. *Room lamp,* 60-*watt* $= \frac{60}{1,000} \times 4 = \frac{1}{4}$ *amp.*
Capacity 1 *hour listening at* 1 *amp per* 1 *hour light.*
Total cell capacity, 40 *amp hour actual.*

Secondly, it is always easier to get silence where the negative main is the live one, possibly because of the capacity of the receiver as a whole, but mainly because of the sensitiveness of the phones or speaker to commutator hum independently of the receiver altogether.

This is alluded to by Mr. Robertson.

Where the + main is earthed this purely magnetic pick up is, of course, absent, and we have the option of connecting the H.T. + to earth, or to the neutral main.

Practically it always proves best to connect the L.T. + back to neutral and the H.T. + to earth.

Thirdly, it is easier to get rid of a true alternating hum than of commutator noises, for one thing the voltage drop available is greater on A.C. supplies and for another the sparking of D.C. machines is absent or smoothed out in the transformers.

Fourthly, if chokes and condensers are used, two chokes and two condensers are enormously more efficient than one of each of the same total values. But a resistance is always more effective than a choke (except in the case of A.C. where the choke works in an entirely different way).

Fifthly, it is better to use a non-metallic than a metallic resistance or choke; for instance, the neon lamp is far more efficient than a combination of lamps of the same resistance, and it is better to get lower voltages by tapping the highest voltage through a resistance, than to use a potentiometer. The L.F. end is far less sensitive to hum than the detector (which requires the least voltage), and by drawing off and further smoothing the highest H.T. supply we both gain efficiency and save expense.

The writer finds that any non-metallic resistance in the form of a pencil is better than a wire wound resistance.

The writer cannot agree that the condensers across the H.T. + and H.T.— take no part in the smoothing.

The use of twelve lamps in series is of course not commercially practicable, and is in any case unduly expensive and easily replaceable by one or two lamps and a series resistance tapped for the different voltages.

Another point here is that no supply company will allow lamps to be used as resistances on the low rate of one penny per unit.

As regards running valves in parallel, in series with resistances, it would be cheaper to put in a D.T.G. as a floating battery than to risk burning out a 16s. valve.

Sixthly, there is no advantage in the use of a potentiometer drawing, say, 0.1 amp from the mains (all of which has to be smoothed) instead of the .02 given by a neon lamp and a condenser with a series resistance for varying the voltage, except that it enables the valves to be lit (somewhat riskily) off the mains.

Seventhly, it is a better proposition to keep the L.T. off the mains entirely and to use the room light for charging the batteries in *series* and to use them on the receiver in *parallel.*

I give herewith a diagram showing the connections of a complete unit of the most economical type, using 4 D.T.G. cells costing less than one accumulator of equivalent total size.

In conclusion, this unit costs nothing to run, the cells are always fully charged and only require topping every six months, and the whole cost of the installation if made at home will not exceed £2 10s., including cells, switches, lamps and sundries. By having four positive and four negative tappings we can vary the positives separately, or as a whole by moving the negative.

The unit is perfectly safe as there are lamps on both mains supplies, and even on a 250-volt main with the negative adjusted to $\pm$120 volts, this is the maximum shock that can be taken from the unit.

Luton. ERNEST J. BATY.

Directory of Sources of Special Information.

To the Editor, E.W & W.E.

SIR,—Just as the practical utility of a book is impaired by the want of an index, so the vast aggregation of knowledge that has been built up and is in many cases being added to day by day is largely lost to mankind owing to the lack of a master-key to its whereabouts. Throughout this country there are numerous centres of specialised knowledge and experience of the most varied description, the existence of which has only to be known for them to prove of great service to the world.

It is with the object of bringing these to light and recording their salient features in concise form that the Association of Special Libraries and Information Bureaux, in collaboration with the Carnegie United Kingdom Trust, has asked me to compile a Directory.

It has been decided to go forward with the printing of a first edition of this Directory at mid-summer, but much still remains to be done. It is recognised that completion in any one subject is well-nigh impossible in so short a time. It would, however, greatly further this end if libraries, organisations, firms and individuals possessing special information on any subject and willing to answer inquiries thereon, which have not yet been in touch with us would communicate with me at 38, Bloomsbury Square, W.C.1.

Yours faithfully,

(Signed) G. F. Barwick, General Editor,
late Keeper of Printed Books,
British Museum.

A New Development in Resistance Amplification.

To the Editor, E.W. & W.E.

Sir,—Mr. Colebrook's article on "Resistance Amplification" in your April issue is most timely, in view of the large amount of attention which the use of extra high anode resistance is receiving, and the widespread misunderstanding of the conditions required for the best results. He has provided clear theoretical and practical data in place of the rather hazy ideas which have been current, and in particular has dealt with the limitations inherent to the method, which have not been clearly set forth hitherto.

There is, however, an aspect of the matter which is of considerable practical importance, and concerning which no information has, as far as I am aware, been published. From the nature of the method, which is applicable only to relatively small input voltages, it follows that the most logical arrangement is to use the high anode resistance to couple the detector to the succeeding valve (and possibly in the next stage also). Now, as Mr. Colebrook has done such valuable work on detector efficiency, it would be particularly interesting to have some correlation of the two subjects; in other words, what conditions must be applied in order to obtain the best overall amplification, taking into account the effect of the resistance on efficiency of rectification?

Again, one must consider the rejection of radio frequencies from the audio stages. This is of great importance in supersonic receivers, but is by no means to be neglected in "straight" sets. The simplest method is to use a condenser of the order of 1,000$\mu\mu$F across the coupling, but, as Mr. Colebrook shows, the capacity here should not greatly exceed that due to the interelectrode capacity, when the anode resistance is of the order of megohms.

By using the more elaborate types of filter the problem is partly solved, but only by adding considerably to the complication of the amplifier. It would appear, therefore, that the use of high anode resistance is subject to greater limitations in the detector stage than in a true audio stage, in cases where the radio frequency is low or the total magnification very high; for the straying of radio frequency currents beyond their proper bounds is one of the most fruitful causes of trouble in such receivers.

Marcus G. Scroggie, B.Sc.

ERRATUM.

"The Horizontal Hertzian Aerial for Transmission," page 145, numbering of Figs. 2 and 3 should be transposed.

Abstracts and References.

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PROPAGATION OF WAVES.

ÜBER DIE BESTIMMUNG DES NEIGUNGSWINKELS ELEKTRISCHER WELLEN UND DIE AUSSCHALTUNG GENEIGT EINFALLENDER WELLEN AM EMPFÄNGER (On the determination of the angle of inclination of electrical waves and the exclusion of inclined incident waves from the receiver).—A. Esau. (*Zeitschr. f. Hochfrequenz.*, 29, January, 1927, pp. 4-10.)

In an earlier paper (*Zeitschr. f. Hochfrequenz.*, 28, August, 1926, pp. 50-53; these abstracts, *E.W. & W.E.*, December, 1926, p. 766), it was shown that the fading phenomena due to changes of polarisation of electric waves can be eliminated by coupling a vertical and a horizontal antenna of suitable form to a common circuit tuned to the incoming wave. The present article deals with the problem of getting rid of the fading caused by inclined waves of differing phase difference entering the receiver. If these rays interfere with one another or with the direct ray arriving at the receiver, the intensity received can alter up to complete extinction, or in telephony, the speech or music conveyed can be distorted. This latter effect has been pointed out by Bown, Martin and Potter (*Proc. Inst. Radio Eng.*, 11, 1926, p. 106).

The solution of the problem consists in securing that the indirect ray when it arrives at the receiver will have no action upon it, the direct ray alone being able to bring the receiver to respond. An ideal solution in which *complete extinction* of all inclined incident rays occurs is not to be found, as this paper shows. By a right choice of the receiving system and angle of inclination, however, a more or less marked attenuation can be attained, which should suffice in the majority of cases to prevent complete vanishing of the intensity and considerably diminish distortion, due to interference.

It is shown in the second part of the article that combinations of vertical undirectional antennæ are most suitable for separating out inclined incident waves at the receiver, their distance apart being chosen so that the ratio d/λ is smaller than about 1/10. The greater the number of antennæ the less will the receiving system they form respond to inclined waves.

In the first part of the article, three possible receiving arrangements employing a vertical and horizontal antenna are found for determining the angle of inclination of an incident wave, namely, vertical frame and straight horizontal wire, vertical and horizontal frames, vertical and horizontal wires; there resulting from the measurement of the currents in both antennæ, the sine, tangent or cotangent respectively of the angle of inclination, according to the arrangement used. A straight vertical wire and horizontal frame will not do, this arrangement yielding instead of the angle of inclination, the angle of rotation of the plane of polarisation, as described in the paper referred to at the outset.

INCLINAISON DES ONDES ET SYSTÈMES DIRIGÉS (Inclination of waves and directional systems).—L. Bouthillon. (*Comptes Rendus*, 184, 24th January, 1927, pp. 190-192.)

As a result of experiments with radio waves of 10-50 metres, it is generally admitted that the rays that are most useful at a great distance are those leaving the transmitter at a relatively small angle with the zenith, some 20° at the most. It also seems to be proved experimentally that antenna systems erected with a view to concentrating the waves in a given direction are much less effective at a great distance than theory would predict. In particular, mention is made of the projector recently set in operation by the Marconi Company at Bodmin, which was expected to radiate practically in a single direction, but is also vigorously received in the opposite direction. In this paper a relation between these two results is established, explaining how it is that in proportion as the useful rays approach the zenith, directional transmitting systems become less and less efficacious from the viewpoint of wave concentration.

The results are given here for the case of the Marconi projector (curtain antenna with parallel reflector), showing that for the Bodmin antenna,

$$\frac{d}{\lambda} = 14.6, \ \frac{d'}{\lambda} = \frac{1}{4},$$

d being the width of the curtain and d' the distance between curtain and reflector.

With the rays horizontal, there is a very narrow principal beam orientated perpendicularly to the curtain in the direction from reflector to curtain, and adjacent beams of very reduced intensity: in the direction opposite the special direction the radiation is nil. As the rays depart from the horizontal and approach the zenith, the principal beam becomes weaker and broader, while the adjacent beams assume more importance, and in the opposite direction to the principal one, a beam of increasing intensity appears, becoming comparable with the principal beam: when the rays become quite vertical, the system is not directional at all.

Inserting numerical values for different angles, the table below shows:—

1. The ratio of the amplitude in the special and in the opposite direction.

2. The aperture of the principal beam.

Angle with the vertical =	90°	30°	14° 30′	7° 11′	0°
$\dfrac{\text{Amplitude in the direction opposite the special one}}{\text{Amplitude in the special direction}}$ =	0	0·42	0·73	0·82	1
Aperture of the principal beam =	7° 50′	15° 44′	31° 46′	60° 20′	360°

ON THE WIRELESS BEAM OF SHORT ELECTRIC WAVES (IV).—S. Uda. (*Journ. Inst. Elect. Engineers of Japan*, No. 462, January, 1927, pp. 26-51.)

The action of a straight metal rod of finite length, erected vertically in the radiation field of a transmitting antenna, is investigated theoretically and tested by experiment; the results are as follows:—

When the natural frequency of this metal rod is equal to the wave frequency, the current induced in it will be in phase with the E.M.F. caused by the wave, and the wave is reflected by the rod. Even if the natural frequency is made somewhat lower than the resonance frequency by increasing the length of the rod, the current induced in it will be lagging behind the E.M.F. and the reflecting action will still be manifest. If, however, the natural frequency is made somewhat higher than the resonance frequency by shortening the rod, the induced current will be leading the E.M.F., and when the phase angle and magnitude of the current reach suitable values, the wave is transferred further forwards beyond the rod. The rod is now acting as a means of converging the wave energy and transmitting it further with more concentration and is therefore now called a wave director.

ON THE WIRELESS BEAM OF SHORT ELECTRIC WAVES (V) (High angle radiation of short-wave beam).—S. Uda. (*Journ. Inst. Elect. Engineers of Japan*, No. 462, January, 1927, pp. 52-62.)

Description of an experimental investigation of the distribution of energy in a vertical plane radiated from a transmitting antenna tuned in different higher harmonics.

The field intensities in various altitudinal directions are measured by the receiving apparatus which is moved along a vertical line. A single vertical metal rod is used as antenna and at first is not earthed. The length of the antenna is varied so that it equals λ, $\frac{3}{2}\lambda$, or 2λ ($\lambda = 266$ cms.) and oscillates in the second, third, or fourth harmonic. Distribution diagrams for these cases are given and curves plotted. The following conclusions are confirmed:—

The wave energy is projected chiefly upwards, practically no radiation being transmitted along the earth's surface. When the length of the antenna exactly equals a wavelength, only one maximum radiation will occur, but when it equals $\frac{3}{2}\lambda$ or 2λ, the wave directed upwards will split into two or three parts and consequently there will be two or three points of maximum radiation.

Experiments were also made with the earthed vertical antenna of length $\frac{3}{4}\lambda$, $\frac{5}{4}\lambda$, $\frac{7}{4}y$, or $\frac{9}{4}\lambda$. In these cases again the radiation projected at high angles is very intense while the energy flowing along the earth is very feeble, also in the two latter cases, when the antenna is excited in the 7th or 9th harmonic, the wave radiated upwards will split into two or three parts.

It is further shown that directional transmission with high angle radiation is readily obtained by using three vertical metal rods making up the trigonal reflecting system. Here the antenna and the three reflectors are made equal to the wavelength and thus they are all excited by the second harmonic oscillation. The distribution curves clearly show that these three reflectors are effective in producing a directional radio wave with high angle radiation. If, in addition to the trigonal reflector, several wave director rods arranged along an inclined line of the direction of maximum radiation are employed, the directivity will be much improved.

SHORT WAVE WIRELESS TELEGRAPHY.—T. Eckersley. (*E.W. & W.E.*, April, 1927, pp. 213-222.)

Abstract of a Paper read before the Wireless Section, I.E.E., 2nd March, 1927.

The paper deals with short-wave practice and theory, the discussion falling into four sections: 1. The aerial transmission characteristics, in particular the computation of vertical polar diagrams; 2. Results of experiments with short-wave direction finding; 3. Results of a series of long-distance transmission tests, on waves between 25 and 10 metres; 4. General theory of ionic refraction, etc.

DISCUSSION ON LONG DISTANCE RADIO RECEIVING MEASUREMENTS AT THE BUREAU OF STANDARDS IN 1925 (L. W. Austin).—K. Sreenivasan. (*Proc. Inst. Radio Engineers*, 15, February, 1927, pp. 155-157.)

It is pointed out that while the Washington observations (monthly averages) on Bordeaux always show an increase in field strength, the curves obtained by Hollingworth (weekly averages) sometimes show as marked a reduction in field intensity. The writer inclines to doubt the increase in every case.

It is agreed that the slight but regular increase in yearly average intensity generally found is probably due to changes in the Kennelly-Heaviside layer, either in average height or in ionisation, possibly connected with changes in solar activity.

MAGNETIC STORMS AND WIRELESS TRANSMISSION.—E. V. Appleton. (*Electrician*, 98, 11th March, 1927, pp. 256-257.)

The existence of a conducting layer in the upper atmosphere has been postulated in the study of terrestrial magnetism to explain its diurnal variations. Such a layer has also been assumed by the radio investigator to account for the facts of wireless transmission. Until recently, however, the evidence presented by the two subjects has contained two important discrepancies: one, that terrestrial magnetism demanded a higher layer conductivity than wireless telegraphy, and the other, the absence of obvious correlation between magnetic and wireless irregularities.

In this article the author shows how these discrepancies have been removed by recent experimental results, and gives a revised interpretation of the data.

THE SUN, THE EARTH'S ATMOSPHERE, AND RADIO TRANSMISSION.—S. Chapman. (*Nature*, 19th March, 1927, pp. 428-429.)

The presence of ions in the upper atmosphere is now known to be of the greatest importance for

radio communication—refracting the waves, absorbing their energy, and, in conjunction with the earth's magnetic field, changing their polarisation. It has been suggested that the source of this ionisation is the penetrating radiation studied by Kolhörster, Hess and Millikan, or the runaway electrons whose probable occurrence during thunderstorms has been pointed out by C. T. R. Wilson, but the author here shows that it is unlikely that the ionisation thus produced compares at all in importance with that due to the sun. He discusses in detail the action of the two independent solar ionising agents: ultra-violet radiation, travelling rectilinearly and reaching only the sunlit hemisphere; and a corpuscular radiation coming from locally disturbed areas on the sun's surface, falling not only on the day side but also bent round to the night side of the earth.

THE CORRELATION OF RADIO RECEPTION WITH SOLAR ACTIVITY AND TERRESTRIAL MAGNETISM. — G. Pickard. (*Proc. Inst. Radio Engineers*, 15, February, 1927, pp. 83-97.)

A full account of the correlation between radio reception, solar activity and magnetic disturbances is not yet possible, owing to insufficient data, and this paper is just a progress report setting forth the results so far obtained and emphasising the importance of systematic long-period observations of radio reception. Various series of observations are tabulated and shown graphically.

THE ABSORPTION OF RADIO WAVES IN THE UPPER ATMOSPHERE.—E. Hulburt. (*Physical Review*, 29, 2, February, 1927, p. 365.)

Abstract of a Paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

The absorption of radio waves in the upper atmosphere, put on one side in the theory of Taylor and Hulburt because of its smallness, has been calculated on the assumption that it results from collisions between the electrons and molecules of the atmosphere. Formulæ are derived for the dispersion and absorption of the variously polarised waves, and quantitative agreement is indicated with observed data of ranges and degradation of intensity with distance from the transmitter.

ATMOSPHERIC ELECTRICITY.

THE ELECTRIC FIELDS OF SOUTH AFRICAN THUNDERSTORMS.—B. Schonland and J. Craib. (*Proc. Royal Society*, 114A, March, 1927, pp. 229-243.)

Evidence of the bipolar nature of thunderclouds is presented, and the strong predominance amongst such clouds of a type in which the upper pole is positive and the lower pole negative. This preponderance of the positive type suggests that Dr. Simpson's theory of the production of the charge by the breaking up of large water-drops in an ascending air current, which would produce a cloud of negative polarity, must either be rejected or radically altered. On the other hand, this positive polarity of thunderclouds is required by Prof. C. T. R. Wilson's theory for the replenishment of the negative charge on the surface of the earth, the ionisation currents between the bases of these clouds and the ground serving to maintain the earth's charge at a steady value in spite of the reverse current flowing in regions of fine weather.

ATMOSPHERIC ELECTRICITY.—L. Bauer. (*Nature*, 26th March, 1927, p. 457.)

Some remarks on Dr. Chree's letter in *Nature* of 18th December, 1926, followed by a reply from Dr. Chree.

COSMIC ASPECTS OF ATMOSPHERIC ELECTRICITY.—L. Bauer. (*Physical Review*, 29, February, 1927, p. 371.)

Abstract of a Paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

There being at present no generally accepted theory to account for the origin and maintenance of the earth's negative electric charge, it is of peculiar interest to study the laws and *modus operandi* of the changes to which atmospheric electricity is subject during the day, year, and from year to year. These changes, which even on meteorologically-undisturbed days are of the order of the absolute values of the atmospheric elements themselves, show remarkable terrestrial and cosmical aspects, *i.e.*, they are in general of the same character and sign at stations both in the northern and southern hemispheres. Recent world-wide observations give further confirmation of these striking facts. A brief discussion is also given of the relation of the atmospheric-electric results to recent measurements of the ozone content of the atmosphere, of the sun's ultra-violet radiation, of radio-reception, and of solar activity.

ON THE EFFECTS OF DUST, SMOKE, AND RELATIVE HUMIDITY UPON THE POTENTIAL GRADIENT AND THE POSITIVE AND NEGATIVE CONDUCTIVITIES OF THE ATMOSPHERE.—G. Wait. (*Physical Review*, 29, February, 1927, p. 372.)

Abstract of a Paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

Simultaneous observations of atmospheric electricity, dust-content, and relative humidity, obtained at the Watheroo Magnetic Observatory, Western Australia, are discussed.

The dust-content series indicate that the potential gradient is approximately doubled for increase of dust-content from zero to 10,000 particles per c.c., and thereafter a very slow increase with increased dust-content. Both positive and negative conductivities decrease about half when the dust-content changes from zero to about 5,000 particles per c.c. and decrease very slowly thereafter with increased dust-content. The ratio of positive to negative conductivity increases with increasing dustiness. The importance of more observations on the behaviour of ions in air is pointed out.

TRANSMISSION.

SOME NOTES ON DESIGN DETAILS OF A HIGH-POWER RADIO-TELEGRAPHIC TRANSMITTER USING THERMIONIC VALVES.—R. Hansford and H. Faulkner. (*Journ. Inst. Electrical Engineers*, 65, March, 1927, pp. 297-326.)

Paper read before the Wireless Section, 1st December, 1926, dealing with certain specific details of design and operation of the Rugby valve transmitter, consisting of the following more or less independent sections :—

1. Consideration of the most suitable type of aerial circuit, from the point of view of the elimination of undesirable harmonic emissions.
2. The design of the electrical proportions of the aerial circuit.
3. The inductance coils for the aerial circuit.
4. Some notes on valve circuit design.
5. Keying and shape of signals.
6. Recent results at Rugby.

SOME EQUIPMENT USED IN TRANSATLANTIC RADIO TELEPHONY.—(*Electrical World*, 26th February, 1927, p. 442.)

Illustrations are shown of the circular bank of 15 water-cooled power amplifier valves at Rocky Point, also an intermediate amplifier group for raising the level of the voice currents from an initial 50 watts to 15kW, and the high-voltage rectifier with 12 diodes each rated at 20kW with a plate current of about 2 amps and a filament current of 41 amps supplied by 22 volts, alternating current.

INTERMITTENT VALVE OSCILLATOR.—L. Taylor. (*Journ. Franklin Institute*, 203, March, 1927, pp. 351-374.)

Account of an investigation of an oscillating circuit maintained by a thermionic valve which oscillates only during certain definite intervals of time, the effect being procured by inserting suitable high resistance and capacitance in the grid circuit.

SPACE CHARACTERISTICS OF ANTENNÆ. — W. Murphy. (*Journ. Franklin Institute*, 203, February, 1927, pp. 289-311.)

The first article on this subject was published in the *Franklin Institute Journal* of April, 1926 (these abstracts, *E.W. & W.E.*, June, 1926, p. 382). The present article deals with the reception characteristics of antennæ; the application of the previously obtained electrostatic field equations to receiving antennæ, by which means induced voltage equations are evolved; the directional effects obtained between airplanes and ground stations as well as between airplanes in parallel flight; and the bearing errors met with when using loop or horizontal antennæ. It is shown that the transmission and reception characteristics of a given antenna are equal and that the induced voltage characteristics obtained for two antennæ are the same regardless of which is transmitting. In conclusion, the effect of antenna combinations in which current and space phase displacements are taken into account are discussed, and equations including the phase displacement angles evolved.

ZUR THEORIE DER EXTREMEN SCHNELLTELEGRAPHIE (On the theory of extremely high-speed telegraphy).—W. Ludenia. (*Eleckt. Nachr. Technik*, 4, 2, 1927, pp. 93-96.)

A mathematical analysis of the damping relations in high-speed transmitting and receiving circuits and the process of multiple telegraphy on one wave.

RECEPTION.

EIN BEITRAG ZUR THEORIE DER NIEDERFREQUENZ-VERSTÄRKUNG MIT WIDERSTANDSKOPPLUNG (A contribution to the theory of low-frequency amplification with resistance coupling).—H. Kafka. (*Zeitschr. f. Hochfrequenz.*, 29, February, 1927, pp. 39-45.)

The object of this paper is to represent the frequency dependence of a low-frequency stage with resistance coupling by means of a locus diagram. With this very clear form of representation, the influence of the different factors that come in, on the amplification and its dependence upon frequency, can be seen much more readily than from formulæ. The first step in the solution of the problem is to obtain the fundamental valve equations, and an expression is found in which the tension relation E_{g2}/E_{g1} is represented by a plane vector, whose value and direction change with the frequency. To represent plane vectors graphically, a rectangular system of coordinates is employed with origin o, whose vertical axis is called the effective axis ω, and horizontal axis the blind axis b. The figure expressing the dependence upon frequency constitutes an objective base for investigating whether this or that resistance combination is the more suitable for a given case, and the relations developed provide starting-points for calculating the circuits. In order to approach as near the actual conditions as possible, the valve capacities and load conditions of the next stage are taken into account.

A NEW DEVELOPMENT IN RESISTANCE AMPLIFICATION.—F. Colebrook. (*E.W. & W.E.*, April, 1927, pp. 195-205.)

A THEORETICAL AND EXPERIMENTAL INVESTIGATION OF DETECTION FOR SMALL SIGNALS.—E. Chaffee and G. Browning. (*Proc. Inst. Radio Engineers*, 15, February, 1927, pp. 113-153.)

The paper presents the theory of detection for both two and three-electrode devices, expressed in terms of the circuit impedances and the first and second partial differential coefficients of the static characteristic curves of the device, taken at the points on the characteristic curves determined by the steady polarising voltages. It is then assumed that the impressed signal is so small that for any given steady voltages these coefficients can be supposed constant within the range of the variations due to the signal voltage. A small signal voltage is defined as one less than 0.05 volt r.m.s.

Boucherot's Constant-Current Networks and their Relation to Electric Wave Filters—A. Bartlett. (*Journ. Inst. Elect. Engineers*, 65, March, 1927, pp. 373-376.)

The circuit arrangements devised by Boucherot to give a constant-current supply from a constant-voltage supply are briefly described, and it is shown that they may be regarded as simple examples of a more general property of all electric filters.

Radio Telegraph Recorder.—A. Jipp. (*Siemens Zeitschrift*, December, 1926.)

A German firm has developed a mechanical Morse recorder, similar to the siphon recorder of trans-oceanic telegraphy, which not only secures reception up to 2,000 letters a minute, but is practically unaffected by atmospheric interference. The instrument is essentially a moving-coil galvanometer, the coil being suspended between two short lengths of steel wire: at the end of the horizontal writing lever, a fine silver tube is fastened, one end of which touches the recording tape, while the other moves in a drop of recording ink maintained by a simple feeding mechanism.

Ein neues Relais fur extrem schwache Ströme (A new relay for extremely weak currents).—H. Richter and H. Gaffcken. (*Zeitschr. f. Techn. Physik*, 7, 12, pp. 601-606.)

There is a description of this very sensitive glow-discharge relay in *Wireless World* of 2nd March, 1927, p. 262.

Loud-Speaker Diaphragms. — N. McLachlan. (*Wireless World*, 23rd April, 1927, pp. 345-350.)

The problem of the vibrating disc is considered, and the influence of diameter on interference effects at high frequencies.

La Soupape Electrolytique (Electrolytic valve).—Y. Doucet. (*Q.S.T. Français et Radio Electricité Réunis*, March, 1927, pp. 14-18.)

Account of the determination of the conditions of optimum efficiency.

High Pressure Powder Contact Rectifier.—J. Lilienfeld and C. Thomas. (*Physical Review*, 29, 2, February, 1927, p. 367.)

Account of a rectifier making use of the known contact combination, aluminium to cupric sulphide. The pressure is of importance with regard to the rectification, and a compression force of about one thousand pounds is supplied by a helical spring. Oscillograms of the current through a resistance load show complete and distortionless full wave rectification, while those of the current through a new filter circuit of inductances and resistances show suppression of the ripple to less than 1 per cent. of the total voltage.

The Resultant Capacity of Aerial Systems employing Series Tuning Condensers.—W. Griffiths. (*E.W. & W.E.*, April, 1927, pp. 206-212.)

VALVES AND THERMIONICS.

The Input Impedances of Thermionic Valves at Low Frequencies. — L. Hartshorn. (*Proc. Physical Society*, 39, 15th February, 1927, pp. 108-123.)

It is shown that accurate measurements of input admittance (or of input impedance) under various conditions can be made by means of the Schering Capacity Bridge. The input circuit is regarded as being equivalent to a condenser with a definite phase angle, ϕ, or "loss angle," $\delta = 90° - \phi$, and the results are expressed by stating the effective capacity and value of $\tan \delta$ for each set of experimental conditions.

A series of experiments made on an *R* valve is recorded, and it is shown that the results are in good agreement with the theoretical investigations of Miller and Nichols. The theoretical investigation has been extended to allow for the effect of dielectric losses in the valve, since these were found by experiment to be rather large, and to have an appreciable effect on the capacity and phase angle of the input circuit.

It is shown that the effective capacity may vary from about $10\mu\mu F$ to $100\mu\mu F$ for an R valve, and the phase angle may vary from about 80° leading to 126° leading, depending mainly on the load in the anode circuit. Values of phase angle greater than 90° correspond to a negative resistance, or negative power factor, and occur when the load in the anode circuit is inductive. The variations of input capacity and phase angle with filament voltage, anode voltage, input voltage, and frequency are also investigated.

Temperature Distribution along a Filament.—V. Bush and K. Gould. (*Physical Review*, 29, February, 1927, pp. 337-345.)

A method has been developed for adapting a new integrating machine to the solution of :—

1. The integral equation which applies to the distribution of thermionic emission along the central portion of a long filament in an evacuated vessel, the effect of the thermionic emission upon the filament temperature being considered.
2. The differential equation which applies to the temperature distribution near the end of a long filament from which the thermionic emission is negligible compared with the filament heating current.
3. The integro-differential equation which applies to the distribution of temperature and thermionic emission along an entire filament heated in an evacuated vessel by a direct current. This takes into account the effects of thermionic emission as well as cooling due to thermal conduction.

All these solutions fully account for the variation of the following quantities with temperature, graphical relations being used throughout: (*a*) thermal conductivity, (*b*) thermionic emission, (*c*) resistivity, (*d*) radiation. The method has been applied to various typical cases of tungsten and thoriated tungsten filaments, and in those cases where an experimental check was possible it was found that the results were in good agreement with the measured quantities.

THERMIONIC VALVE MANUFACTURE.—G. Paterson. (*Electrician*, 98, 11th March, 1927, pp. 262-263.)

Abstract of a paper read at the Royal Society of Arts on 16th February, 1927.

MICROPHONIC NOISES.—P. Tyers. (*Wireless World*, 9th March, 1927, pp. 304-305.)

A note on the mounting of valves.

ÜBER DEN ELEKTRONENAUSTRITT AUS METALLEN UNTER WIRKUNG HOHER FELDSTÄRKEN (On electronic emission from metals under the influence of high field intensities.). — G. Hoffmann. (*Ann. d. Phys.*, 82, 2, 1927, pp. 254-256.)

Some remarks on Rother's paper (*Ann. d. Phys.*, 81, 1926, p. 317).

INTERPRETATION OF DATA DEALING WITH THERMIONIC EMISSION.—W. Ham. (*Physical Review*, 29, 2, February, 1927, p. 364.)

Abstract of a Paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

PHENOMENON OF DIRECT-CURRENT SELF-EXCITATION IN VACUUM TUBE CIRCUITS AND ITS APPLICATIONS.—N. Minorsky. (*Journ. Franklin Institute*, 203, February, 1927, pp. 181-209.)

Theoretically the application of valves in direct-current circuits is very attractive, but the difficulties inherent in existing schemes of D.C. amplification are considerable. The purpose of the present investigation is to eliminate some of these difficulties, particularly the necessity of using very large grid batteries specially difficult to adjust when several stages of amplification are used. Incidentally, it was discovered that under certain conditions the valve system acquires entirely new properties compared with those of an ordinary amplifier; namely, its performance can become abrupt, similar to the action of an ordinary contact, which lends itself to important applications.

MEASUREMENTS AND STANDARDS.

PRECISE DETERMINATION OF FREQUENCY BY MEANS OF PIEZO-ELECTRIC OSCILLATORS.— J. Tykocinski-Tykociner. (*Physical Review*, 29, 2, February, 1927, p. 366.)

Abstract of a paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

The oscillating current whose frequency is to be determined is inductively superimposed upon the oscillations of a piezo-electric oscillator. The plate current of the driving thermionic oscillating valve is compensated by a potentiometer arrangement so that the current variations can be observed by a microammeter. The relation between the plate current of the piezo-electric oscillator and the exciting frequency was investigated experimentally. The curves show a sharp current maximum and minimum with an intermediate steep line crossing the zero current abscissa. The point of intersection corresponds to resonance. If the exciting frequency exactly equals the fundamental frequency or a harmonic of the piezo-electric oscillator, no influence whatever is exerted on the plate current; but a deviation of 1.15 of the frequency measured can still be detected when the quartz crystal is clamped between two electrodes; with the crystal free, frequency variations less than one in a million are detected by a violent vibration of the microammeter pointer. The plate current variation in the measured circuit is of a different character and less pronounced.

FACTORS AFFECTING THE CONSTANCY OF QUARTZ PIEZO-ELECTRIC OSCILLATORS.—E. Terry. (*Physical Review*, 29, 2, February, 1927, p. 366.)

Abstract of a paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

A study is made of the effect of mechanical stresses, temperature, and circuit constants upon the frequency of an oscillating plate of quartz connected in the usual way across the grid-filament elements of a valve, a tuned resonance circuit being placed in series with the plate. Frequency changes were measured by determining the change in pitch of the audio-frequency beat note between this oscillator and a similar one furnishing a constant frequency. Various kinds of deformation were produced by loading the plate at different places and also by subjecting it to different air pressures.

IMPORTANCE OF LABORATORY MEASUREMENTS IN THE DESIGN OF RADIO RECEIVERS.—W. MacDonald. (*Proc. Inst. Radio Engineers*, 15, February, 1927, pp. 99-111.)

The thirteen fundamental measurements of a receiver are given as follows:—

1. Voltage step-up of input coupling transformer.
2. Voltage step-up of 1st valve and coupling transformer.
3. Voltage step-up of 2nd valve and coupling transformer.
4. Voltage step-up of following stages.
5. Complete R.F. amplification from input coupling-coil to the detector.
6. Resonance characteristic of input coupling transformer.
7. Resonance characteristic of 1st stage transformer.
8. Resonance characteristic of 2nd stage transformer.
9. Resonance characteristic of following stage transformers.
10. Resonance characteristic of complete R.F. amplifier from input to the detector.
11. Amplification and frequency characteristics of 1st audio transformer.
12. Amplification and frequency characteristics of other audio transformers.
13. Relative frequency characteristics of complete audio system including detector.

The apparatus required is described and the manner in which the experiments are carried out.

A NEW LOSS-MEASURING DEVICE AND ITS APPLICATION TO HIGH-FREQUENCY MEASUREMENTS.—P. Cooper. (*Philosophical Magazine*, 3, March, 1927, pp. 625-638.)

Description of a method employing a fixed resistance in series with a variable condenser. The fixed resistance consists of a single straight wire of the smallest available gauge, and the change in frequency accompanying the use of a variable condenser in series with this resistance is compensated by a second condenser.

EINE METHODE ZUR BESTIMMUNG EXTREM HOHER WIDERSTÄNDE UND KAPAZITÄTEN MITTELS KIPPSCHWINGUNGEN (A method for determining extremely high resistances and capacities by means of tilting oscillations).—E. Kurz. (*Archiv. f. Elektrotechnik*, 17, 4, pp. 413-415.)

APPAREIL À LECTURE DIRECTE POUR LA MESURE DES CHAMPS MAGNÉTIQUES—GAUSSMÈTRE (Direct-reading instrument for measuring magnetic fields. A gaussmeter).—G. Dupouy (*Comptes Rendus*, 184, 14th February, 1927, pp. 375-377.)

A crystal of iron carbonate is mounted so that it can move about a suitably chosen axis. When it is placed in a uniform magnetic field, it is subjected to a couple proportional to the square of the field tending to orientate it. This couple is balanced by an opposing couple due to the torsion of a thread or spiral spring attached to a pointer moving over a graduated scale. For every value of the field there is a certain position of equilibrium which can be read off on the dial.

MEASUREMENT OF EARTHING RESISTANCES. (*Electrician*, 18th March, 1927, pp. 288-289.)

TECHNIQUE OF THE DUFOUR CATHODE RAY OSCILLOGRAPH FOR THE STUDY OF SHORT TIME OCCURRENCES.—G. Harrington and A. Opsahl. (*Physical Review*, 29, 2, February, 1927, p. 364.)

Abstract of paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

Methods, circuits and procedure are set forth for using the Dufour plate-in-vacuum cathode ray oscillograph for the investigation of phenomena of such short time duration as to preclude the effective use of any other known oscillograph.

A MULTI-RANGE ABSORPTION CIRCUIT.—A. Castellain. (*Wireless World*, 23rd March, 1927, p. 357.)

Description of a simple method of checking wavemeter calibration.

GENERAL PHYSICAL ARTICLES.

SUB-FUNDAMENTAL PIEZO-ELECTRIC VIBRATIONS IN QUARTZ PLATES.—J. Harrison. (*Physical Review*, 29, 2, February, 1927, p. 366.)

Abstract of a paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

With a new type of piezo-electric crystal mounting, it has been found possible to obtain piezo-electric reactions of very much lower frequency than that of the transverse fundamental, first described by Cady. The "transverse fundamental" is the frequency of the compressional wave in the direction of the largest dimension of the plate, both ends being free. The new mode of vibration is also different from any previously observed in that it is dependent to a large degree on more than one crystal dimension. The crystal mounting is so designed that the electric field is applied to two areas which are symmetrically disposed with respect to the longitudinal axis of the quartz plate, and the polarities in the quartz are in opposite directions. With the electric field applied in this manner, piezo-electric crystals operate successfully either as resonators or as oscillators at this subfundamental frequency. The luminous glow emitted by crystals when resonating in a low pressure chamber, lately described by Giebe and Scheibe (*E.T.Z.* 13, 380), can also be observed at the subfundamental frequency, the luminosity presenting striking peculiarities which still await explanation.

ÜBER PIEZO-ELECTRISCHE KRISTALLE BEI HOCHFREQUENZ, II (On piezo-electric crystals at high frequency, II.—A. Meissner (*Zeitschr. f. techn. Physik*, 8, 2, 1927, pp. 74-77.)

The relation between optical and mechanical directions of rotation and piezo-electric charge is discussed. A structural model of quartz is given, and the difference between α and β quartz shown. Piezo-electricity is explained by the pressure and tension applied displacing the atomic charges of a structural element from their position of equilibrium, thus producing the piezo-electric charges. Pyro-electricity is explained by an unequal displacement of the silicon and oxygen atoms from the position of equilibrium with rise or fall of temperature. From the model it is seen that the rotation of the plane of polarisation of light is effected probably through the silicon atoms alone.

SPECTROGRAPHIC OBSERVATIONS OF THE SECOND GREEN LINE OF THE AURORAL SPECTRUM.—L. Vegard. (*Nature*, 119, 5th March, 1927, p. 349.)

A spectrogram obtained for the second green line is shown, which the author states confirms his view with regard to the origin of the auroral spectrum. It is concluded that what is called the second green line is not a single line, but consists of a group of lines, which is also the case with the N_2 line from solid nitrogen.

PROPAGATION OF ELECTROMAGNETIC WAVES ALONG CO-AXIAL CYLINDRICAL CONDUCTORS SEPARATED BY TWO DIELECTRICS.—N. Frank. (*Physical Review*, 29, 2, February, 1927, p. 365.)

Abstract of a Paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

A solution of Maxwell's equations for the cable problem.

ÜBER DIE MESSUNG DER GESCHWINDIGKEITS-AMPLITUDE UND DER DRUCKAMPLITUDE IN SCHALLFELDERN (On the measurement of the velocity and pressure amplitude in sound fields.—E. Meyer. (*Elect. Nachr. Technik*, 4, 2, 1927, pp. 86-90.)

For the velocity measurement the Rayleigh disc is employed, and for the pressure measurement a condenser-microphone in a new compensating circuit-arrangement. Comparison measurements carried out in open sound fields yielded satisfactory agreement.

THE DIRECT COMPARISON OF THE LOUDNESS OF PURE TONES.—B. Kingsbury. (*Physical Review*, 29, February, 1927, p. 373.)

Abstract of a Paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

Tests showed that if the amplitudes of pure tones are increased in equal ratios, the loudness of low frequency tones increases much more rapidly than that of high frequency tones for frequencies up to 700 cycles when the rate becomes nearly uniform. The variability of the data was separated into a factor expressing dissimilarity of ears and another expressing errors of observers' judgment: dissimilarity of ears was found to cause more variation than errors of observers' judgment.

SUR LES PROPRIÉTÉS DIÉLECTRIQUES DES GAZ IONISÉS (On the dielectric properties of ionised gases).—H. Gutton and J. Clément. (*Comptes Rendus*, 184, 21st February, 1927, pp. 441-443.)

Owing to the interest of this question for the investigation of the propagation of electro-magnetic waves in the upper atmosphere, the authors undertook to make measurements employing continuous oscillations, separating the effects of ionisation on the period and the damping of a resonator.

The resonator of wavelength 408.5 cm. consisted of two sheets of copper (20.2 × 4 cm.), 4 cm. apart, joined by a copper wire 92 cm. long, in the middle of which a thermo-electric junction was inserted, joined to a galvanometer. A valve oscillator whose wavelength could be varied was placed near the resonator. By observing the deviations on the galvanometer for different wavelengths, the resonance curve of the resonator could be traced and its period of oscillation found. A glass tube, through which a discharge could be passed to ionise the gas it contained, was placed parallel to the longer sides of the plates of the condenser. For different pressures and ionisations, the wavelength was measured on which the resonator was tuned and the current of resonance.

At the lowest pressures, weak ionisation decreases the wavelength of the resonator and this diminution indicates an apparent decrease of the dielectric constant below unity. Eccles' theory (*Proc. Roy. Soc.* 87, 1912, p. 79) explains this diminution simply by the inertia of the electrified particles to determine the motion of these particles in the oscillating electric field. By increasing the ionisation, the wavelength changes fairly suddenly to a value greater than that corresponding to the strongly ionised gas, thus indicating an increase of the dielectric constant. The change takes place by ionisations causing very marked damping in the resonator. This can only be explained by bringing in quasi-elastic forces, which could result from the mutual actions of the ions and the movements they call forth. When the ionisation is reached for which they compensate the forces of inertia, the sign of the difference of phase between the electric force and the elongation of the oscillations of the electrified particles becomes reversed, which changes the direction of variation of the dielectric constant. The amplitude of the oscillations then becomes very great and calls forth the strong damping of the resonator observed. Lastly, at the highest pressures, forces analogous to friction have the preponderating influence, and curves of the same shape are found as those obtained for an electrolytic solution of increasing concentration.

THEORY OF THE MAGNETIC NATURE OF GRAVITY.—C. Sagui. (*Physical Review*, 29, February, 1927, p. 371.)

Abstract of a paper presented at the Philadelphia meeting of the American Physical Society, December, 1926.

The only physical reality considered necessary is the electromagnetic field. A ray of light is thought of as formed of a series of extremely small electrical resonators without ohmic resistance. In such a resonator a sine disturbance once started will go on without end. A transmitting medium for the energy is not considered necessary. The electromagnetic waves would consist of a sort of magnetic quanta moving to and fro. Matter would be built up similarly of electrical resonators, so that the gravitational force would be represented by the integral value of all the magnetic quanta of the elementary resonators moving to and fro about the body in a radial direction, at a distance which should be a function of the total number of resonators composing the body in question. Thus the gravitational field would not be infinite, but limited by the mass of the body itself. A ray of light going through a gravitational field of such a kind must modify its frequency within certain limits. A second modification of its frequency would result from the motion of the earth, in such a way that when the motion was in the same direction as that of the ray the frequency would become smaller.

WHAT IS ELECTRICITY ?— (*Electrician*, 25th March, 1927, p. 316.)

Abstract of the Faraday Lecture delivered by Prof. W. M. Thornton at the Institution of Electrical Engineers on 17th March, 1927.

MAGNETIC INDUCTION IN CONTINUOUS MEDIA.—C. Burch and N. Ryland Davis. (*Nature*, 119, 5th March, 1927, p. 353.)

THE QUANTUM THEORY OF THE EMISSION AND ABSORPTION OF RADIATION. — P. Dirac. (*Proc. Royal Society*, 114A, March, 1927, pp. 243-265.)

STATIONS: DESIGN AND OPERATION.

United States. (*Electrical Review*, 18th March, 1927, p. 436.)

Station WRNY, in New York City, is preparing to transmit with a buried aerial. The aerial will be drawn through a terra-cotta pipe buried about 6 ft. underground at Coytesville, N.J., where the transmitter is located. During the war extreme ranges were obtained by underground transmission, and WRNY will be the first station in America to broadcast on such an underground aerial.

A report issued at Washington, D.C., by the United States Department of Commerce, says that there are 164 broadcasting stations in Europe, over 700 in the United States, 85 in the remainder of North America, 38 in South America, 16 in Asia, 28 in Oceania, and 9 in Africa.

Radio Control for America.—(*Electrician*, 98, 11th March, 1927, p. 275.)

The Radio Control Act just signed by President Coolidge empowers a Commission of five to establish broadcasting in the United States on the same lines as now prevailing in Europe. At present there are 733 broadcasting stations operating on a waveband which can accommodate only 89.

Broadcasting in South Africa.—(*Electrician*, 18th March, 1927, p. 308.)

Arrangements have been made between the Minister of Posts and Telegraphs of South Africa and the African Theatres, Ltd., whereby broadcasting in Johannesburg will be resumed. A company to be called the African Broadcasting Co., Ltd., will take over the Johannesburg station this month, when shares will be offered to the public. The Government will have two seats on the directorate, and a third seat will be allocated to the Transvaal Radio Society.

German Competition Abroad.—(*Electrician*, 25th March, 1927, p. 340.)

The German Telefunken firm has been successful in obtaining the contract for the new wireless station at Bangkok. There have been three stations in that country for a number of years, but none is capable of transmitting messages effectively to Europe. It has now been decided to build a station for short wave, duplex, and high-speed working between Siam and Europe, and tenders were obtained from the leading British, French, and German companies.

Italy: Broadcasting Control.—(*Electrical Review*, 25th February, 1927, p. 303.)

The Department of Overseas Trade learns from a reliable source that a Commission for the control of broadcasting services has been set up in Rome by Royal Decree. In addition to control, the Commission is charged with examining and reporting on the most suitable methods of developing and improving broadcasting from technical, artistic, and educative points of view.

Peru: New Regulations.—(*Electrical Review*, 4th March, 1927, p. 349.)

The Government having taken over all broadcasting in Peru, station OAX has become State property and new regulations have been issued by the Administration of Posts, Telegraphs and Wireless applying to all receiving sets. It is pointed out that a licence does not authorise the use of a set for commercial purposes, that single-wire antenna must not be over 100 ft. long nor double wire over 140 ft., and that the owner of a set may make no use whatever of any information so received.

Poland: New Station.—(*Electrical Review*, 18th February, 1927, p. 261.)

The newest European long-wave station is that at Warsaw, built by the Marconi Co., for the Polish Broadcasting Co. Power is obtained from the city supply at 3,000 volts, three-phase, being transformed at the station to 210 volts. The transmitter, which is designed on the same lines as that at Daventry, works on 1,013 metres with an input of 10kW to the main oscillator valve. The aerial is carried on two self-supporting lattice steel masts 75 metres high.

Turkey: First Station.—(*Electrical Review*, 18th March, 1927, p. 436.)

Turkey has installed the first broadcasting station of the Near East. The studio is in the G.P.O. Stamboul and is linked to the transmitter in Osmanie by nine miles of cable. The station was constructed by the Compagnie Générale de Télégraphie sans Fil, Paris, with a power of 6kW, and began operations last month.

Short-Wave Beam Transmission.—(*Electrician*, 25th March, 1927, pp. 319-320.)

Description of the equipment of the transmitting station near Grimsby, and the receiving station near Skegness, erected for the British Post Office, by the Marconi Company, for communication with India and Australia.

MISCELLANEOUS.

Sur la Télévision. Premiers Résultats dans la Transmission des Images Animées (On television; first results in the transmission of moving pictures).—Belin and Holweck.—(*Comptes Rendus*, 184, 28th February, 1927, pp. 518-520.)

The authors describe their method of effecting television, in which the cathode-ray oscillograph is employed for receiving, and the first results obtained.

Television.—(*E.W. & W.E.*, April, 1927, pp. 239-240.)

Contribution to the discussion of Mr. Baird's paper before the Radio Society, by Mr. Dénes von Mihály, of Hungary.

Phototelegraphy.—T. Thorne-Baker. (*E.W. & W.E.*, April, 1927, pp. 229-238.)

A Tour Round Savoy Hill.—(*Wireless World*, 9th, 16th and 30th March, 1927.)

Parts V, VI and VII, dealing respectively with the Control Room, arrangements for Simultaneous Broadcasting, and Studio Organisation and rehearsal of Programmes.

Glyptal.—H. Warren. (*Electrician*, 18th March, 1927, pp. 286-287.)

Description of a new synthetic resin which is a distinct improvement on the phenol-formaldehyde resins in respect of resistance to arcing and discharge flexibility, and ability to bond mica.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto - Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

MALLONGONDA SENFADENA TELEGRAFIO.

Resumo de prelego legita de S-ro. T. L. Eckersley ĉe la Senfadena Sekcio de la Institucio de Elektraj Inĝenieroj, Londono, je 2a Marto, 1927a.

La prelego donas ĝisdatan revuon pri mallongonda praktikado. En la unua parto oni diskutas antenajn sendajn karakterizojn, speciale la kalkuladon de vertikalaj polusaj diagramoj, kiuj montras la okazojn por vertikalaj kaj horizontalaj paroj. En la dua parto, direkto-trovaj eksperimentoj je mallongaj ondoj estas priskribitaj. Eksperimentoj per "formato-de-cifero-ok" kaj kardioidaj diagramoj pri apudaj kaj malapudaj stacioj estas diskutitaj. Oni konkludas, ke la foresto de minimumoj ĉe la kadro ("cifero-de-ok") estis kaŭzita ĉefe pro horizontala polusita radio, kiel ĉe longaj ondoj, kaj ke la plimulto de la radioj sekvis la grandan cirklan vojon kaj frapis la ricevilon preskaŭ paralele je la tero. En la tria sekcio, sendaj provoj estas pritraktitaj je ondlongoj de 25 ĝis 10 metroj, kaj rezultaj kurvoj je sendadoj (al Aŭstralio, Kanado, k.t.p.) estas montritaj. Grava konkludo estas, ke la trafpovo de taglumaj signaloj varias proksimume proporcie laŭ la kvadrato de la frekvenco.

La kvara parto de la prelego estas dediĉita tute al teoria diskutado, kiam la aŭtoro disvolvas teorion de maldensiĝo, kaŭze de absorbo ĉe la supra tavolo, kaj diskutas la diferencon inter sendadaj kondiĉoj por longaj kaj mallongaj ondoj tage kaj nokte.

Mallonga raporto pri la diskutado, kiu sekvis la legadon de la prelego, estas ankaŭ presita.

PROPRECOJ DE CIRKVITOJ.

LA REZULTANTA KAPACITO DE ANTENAJ SISTEMOJ UZANTAJ SERIAGORDAJN KONDENSATOROJN. —W. H. F. Griffiths.

La aŭtoro unue aludas al antaŭa artikolo (en Decembra numero) pri la leĝoj de rezultanta kapacito de du kondensatoroj serie konektitaj. Oni montras ke, rilate al anteno kaj seria kondensatoro, la kutima leĝo pri du kondensatoroj seriaj ne povas esti ĉiam aplikita.

La aŭtoro poste traktas pri diversaj ekzemploj de aldona induktanco kaj seria kondensatoro, ilustranta la kalkulojn per kurvoj de indukta, kapacita kaj tuta reaktanco ĉe la diversaj ekzemploj.

Oni konkludas ke, se seria antenagorda kondensatoro estas desegnita (traktanta la antenan kapaciton nur kiel fiksvaloran kondensatoron serian), ĝia desegna leĝo estos, ĝenerale, proksimume korekta por ĉiuj valoroj de aldona induktanco pligrandaj ol duoble je la induktanco de la anteno, kaj treege proksimume korekta kiam uzita kune kun bobenoj dekoble pligrandaj ol la antena induktanco.

RICEVADO.

NOVA EVOLUIĜO JE REZISTANCA AMPLIFADO.— F. M. Colebrook.

La artikolo diskutas la sistemon (ŝulditan al von Ardenne kaj Heinert) de la uzado de anodaj rezistancoj megomgrandaj anstataŭ ol la kutimaj 50,000 ĝis 100,000-omaj, kiam oni uzas rezistanc-kapacitan kuplon por malaltfrekvenca amplifado. La ĝenerala teorio de valvo kun rezistanco en la anoda cirkvito estas diskutita, kaj oni montras, kiel la valoroj de interna kaj ekstera rezisteco en la nova praktiko produktas bezonitan longecon de rekta karakterizo. Oni ankaŭ montras, ke la ordinara esprimo $\frac{R}{R_a \times R}\mu$, kunkonsiderante la modifitan valoron de R_a sub la novaj kondiĉoj. Funkciaj karakterizoj de diversaj valvoj estas montritaj, notinda punkto estante la ebleco de konsiderinda malgrandiĝo de normala filamenta kurento, kaj konservado de ambaŭ alt-tensia kaj malalt-tensia fontoj.

La aŭtoro tiam pritraktas la aplikon al multŝtupaj amplifikatoroj. La efektoj de elektrodaj kapacitoj estas diskutitaj, kaj ekvivalenta cirkvito por kupla ŝtupo montrita, per kio la valoro de la kupla kondensatoro estas kalkulita.

Oni konkludas, ke 80 ĝis 95 procento de la voltkvanta faktoro de la valvo estas obtenebla, kaj ke malaltfrekvenca amplifado per ĉi-tiu metodo estas preskaŭ tute libera de amplituda aŭ frekvenca distordado se la konstrueroj estas de taŭgaj dimensioj. Sugestitaj valoroj estas:—

Anodaj Rezistancoj—1 ĝis 2 megomoj por normalaj valvoj, 2 ĝis 3 megomoj por alt-μ valvoj.
Kradaj Rezistancoj—3 ĝis 5 megomoj.
Kuplaj Kondensatoroj—1,000 ĝis 2,000$\mu\mu$F.

DIVERSAĴOJ.

RESUMOJ KAJ ALUDOJ.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

MATEMATIKO POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto traktas pri la Binoma Teoremo kaj Eksponenciala Serio, kaj finas Parton I de la originala temdividigo de la aŭtoro.

FOTO-TELEGRAFIO.—Raporto pri lekcio kaj demonstracio ĉe la Radio-Societo de Granda Britujo de S-ro. T. Thorne Baker, M.I.R.E., F.Inst.P., F.R.P.S., je 23a Februaro, 1927a.

La lekcianto unue diskutas fruajn eksperimentojn kaj rezultojn je fototelegrafio, kaj la uzadon de seleniaj kaj fotoelektraj ĉeloj. La duontona kliŝo (uzita por ordinara presado) estas poste diskutita, kaj frua metodo sendi per kodo estas priskribita. Poste, fruaj eksperimentoj de Korn kun seleniaj ĉeloj, sekvita de la Belin'a sistemo de reliefa presado de la bildo sendota, kiu estas cilindrigita kaj skribita per stiluso.

Post diskutado pri la Amerikaj sistemoj de Ives kaj de Ranger, la lekcianto priskribis kaj demonstraciis aparaton de sia propra evoluigo. Dum la demonstracio, bildo estis sendita per radio trans la lekcia teatro.

La artikolo estas bone ilustrita per ekzempleroj de bildoj sendita per la diversaj metodoj, inkluzive tiun senditan ĉe la demonstracio, kaj per diagramoj klarigantaj la sistemojn priskribitajn.

TELEVIDADO.

Kontribuaĵo de S-ro. Dénes von Mihály, de Hungarujo, al la diskutado pri la prelego pri ĉi tiu temo de S-ro. J. L. Baird, ĉe la Radio-Societo de Granda Britujo (publikigita en *E.W. & W.E.*, Decembro 1926a). La skribinto kritikas diversajn el la diroj de S-ro. Baird, inkluzive la agadon de vida purpuro, fendetojn en la turniĝanta disko, rapideco de disko, k.t.p.

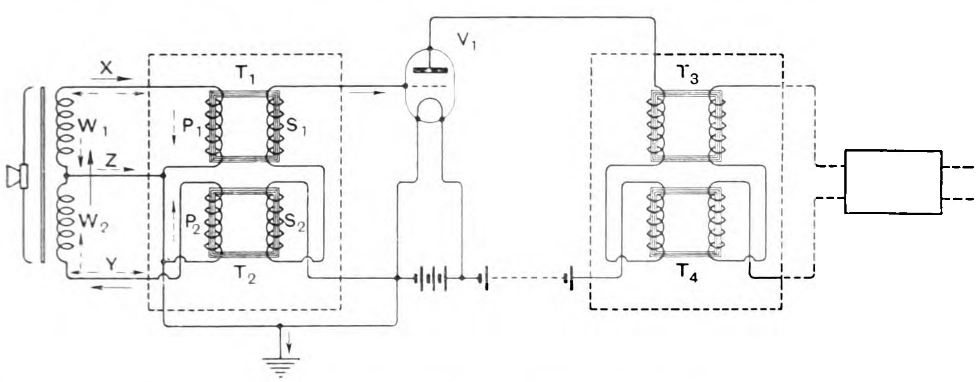
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

MICROPHONE AMPLIFIER CIRCUITS.

(*Application date, 9th November*, 1925. *No.* 266,029.)

E. A. Graham and L. H. Paddle describe in the above British Patent some microphone amplifier circuits in which means are provided for eliminating induction effects and so-called reaction effects between stray fields between the output and input circuits. The invention relates to a centre point earth system in which two closed core transformers mounted side by side are used in the input and output circuits of the valve. The arrangement of the particular circuit is shown in the accompanying illustration. The microphone is of the magnetophone type comprising a centre tapped output, such, for example, as two windings W_1 and W_2. The input of the amplifier consists of two transformers T_1 and T_2. The specification states that these are placed side by side so that the fields are in the same sense. The secondaries S_1 and S_2 of the two transformers are connected in series, and are connected between the grid and filament of the valve V_1. The primaries of the transformers P_1 and P_2 are also connected in series and the two outers are connected by leads X and Y to the microphone terminals, while the centre point of the primaries is connected to the centre point of the magnetophone by a lead Z which is earthed. The output circuit of the valve contains transformers T_3 and T_4 connected in series, no centre point being employed. It will be obvious that should the leads X, Y, Z lie in any stray field any

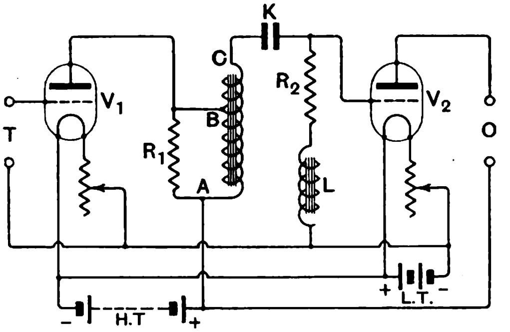


currents induced in the system will balance out so far as the secondary potentials of the transformers T_1 and T_2 are concerned. In other words, the effect of any induced current will not be amplified by the valve V_1. Microphone potentials, however, will not balance out, and will produce potentials across the secondary of the input transformer, which will be subsequently amplified by the valve. The specification also states that it is necessary when using long microphone leads to use earthed sheathed wires, the sheath being connected to the centre point.

AN AUTO-COUPLED TRANSFORMER.

(*Application date, 23rd October,* 1925. *No.* 264,910.)

A special type of auto-coupled intervalve transformer is described in the above British Patent Specification by E. A. Graham and L. H. Paddle. The particular circuit arrangement which is claimed in the invention is shown in the accompanying diagram. The amplifying valve V_1 is provided

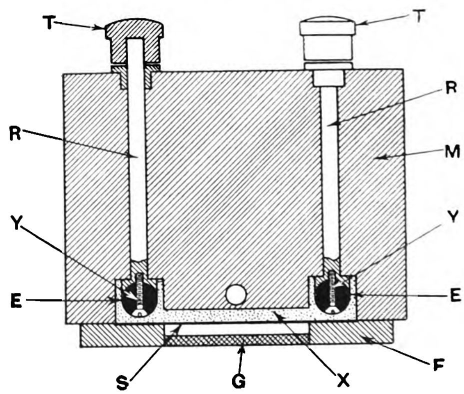


with input terminals T, while the anode circuit contains the primary winding AB of an auto-coupled transformer. The primary winding AB is further shunted by a resistance R_1. Since the transformer is auto-coupled a stopping condenser must, of course, be included between the high potential end of the secondary winding, *i.e.*, C, and the grid of the next valve. Accordingly, a condenser K is inserted as shown, and this necessitates the use of a grid-leak R_2, which is connected in series with a low frequency choke L. The output of the second valve V_2 is shown at O, which can include the primary winding of another similar transformer arrangement. The specification is fairly detailed, and includes several modifications. In another arrangement the transformer is provided with tappings, so that various ratios and degrees of voltage amplification can be obtained. In yet another modification the full winding is shunted by a resistance or potentiometer, the sliding arm of which is connected to the coupling condenser, and, therefore, controls the voltage which is applied to the grid of the next valve.

ANOTHER REISZ MICROPHONE.

(*Application date, 11th August,* 1926. *No.* 258,542.)

E. Reisz describes in the above British Patent a modification of the type of microphone which he has previously developed. It is mentioned in the specification that the response of the previous type of microphone is affected very materially by the size of the granules. If the granules are comparatively large there is appreciable space between them, which allows the sound waves at the higher frequencies to be absorbed, thereby doing no work on the granules as a whole, and lowering the sensitivity of the microphone at the higher frequencies. Also the thickness of the layer of the carbon has a marked effect upon the frequency characteristic. The present invention overcomes these difficulties by using a mixture of granules of various sizes, very fine dust being mixed with two sizes of granules so that the air spaces between the dust and the granules are filled up. It is stated that a satisfactory mixture consists of 47 per cent. of grains of 0.07 mm. diameter, and 22 per cent. of dust not exceeding 0.0015 mm. diameter, the remainder consisting of grains of intermediate sizes. The accompanying diagram shows a cross section of a microphone incorporating a carbon layer of this type. The microphone consists of a block M of marble or other



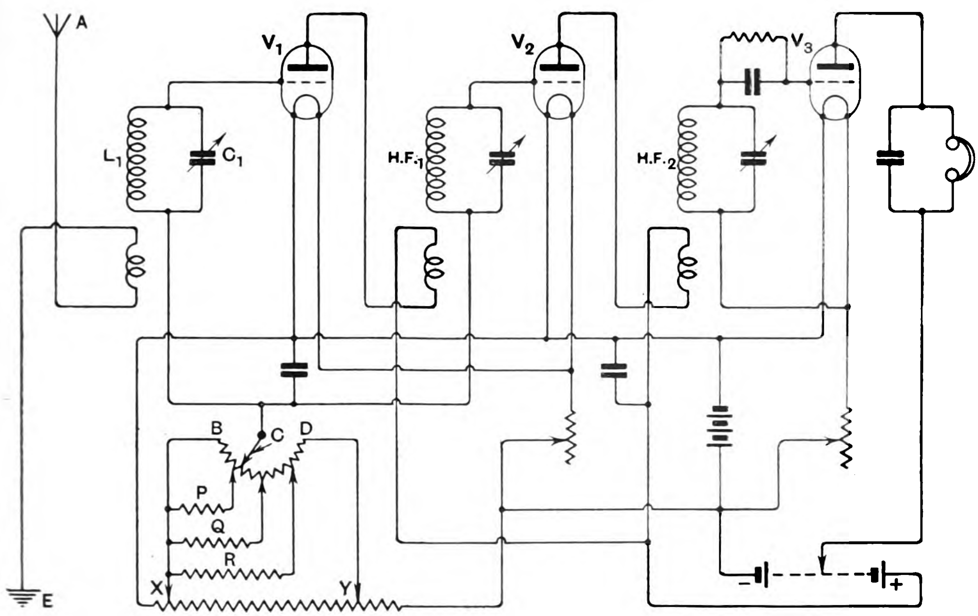
solid material, a portion of the front of which is removed at X and filled with the carbon mixture previously described. Two further recessed portions shown at Y contain electrodes E of carbon or non-oxidisable metal connected by rods R to terminals T located at the back of the microphone. The granules are held in position by means of a thin sheet of rubber S so stretched that the natural period is below 50 cycles per second. The front of the rubber is then covered with gauze G fixed to a frame F so proportioned that the frame lies directly in front of the carbon or other electrodes E. This is necessary so that the sound waves are prevented from falling directly on the electrodes, which might tend to vibrate and render the microphone resonant at their frequency.

CONTROLLING REGENERATION.

(*Convention date* (*U.S.A.*), *4th June,* 1925. *No.* 253,072.)

A method of controlling regeneration is described in the above British Patent by the Lovejoy Corporation and D. R. Lovejoy. The method refers

to controlling the regeneration by damping the input circuits of a series of cascaded valves by applying a positive potential to the grid. The specification points out that the positive potential which is sufficient just to prevent the maintenance of continuous oscillations varies with the ratio of the inductance and capacity in the tuned circuit, and is, therefore, not constant for all settings of the tuning condenser. According to the invention, however, the tuning control and the potentiometer control are mechanically linked. The accompanying diagram should make the scheme quite clear. Here the aerial circuit AE is coupled to the input circuit L_1 C_1 of the first valve V_1. The output of this valve is coupled to the next amplifying valve V_2 by means of a high frequency transformer HF_1, containing a tuned secondary, a second high frequency transformer HF_2 being used between the second amplifier and the detector valve V_3. The lower end of the tuned input circuit of the valve V_1 and the lower end of the secondary winding of the transformer HF_1 are not connected directly to the filament, but to the slider arm C of a potentiometer BCD. The ends BD of the potentiometer BCD are not connected directly across the filament leads of the valve, but across two variable tappings X and Y on a resistance connected across the filament supply so that the actual potential drop across the potentiometer BCD can be finely regulated. The specification points out that by mechanically linking a condenser shaft with the potentiometer arm the relationship between the change of capacity and potential difference between the arm and one end of the potentiometer may not fulfil the required law which is necessary for stabilisation. In order to bring this about it will be necessary to wind the potentiometer with resistance wire of varying specific resistance, or adopt similar means, so that for a given angular displacement the change in resistance would not be a linear function. According to the invention, however, this law is fulfilled by connecting in parallel with the potentiometer BCD auxiliary resistances P, Q, and R arranged as shown. This is in effect equivalent to winding the potentiometer in sections each having different ohmic resistances. The remaining portion of the circuit is quite normal, and is, therefore, not described in detail. Another modification of the invention utilises a similar principle, in which a filament rheostat can be linked with another control so as to bring about a reduction of amplification by dimming the filament.

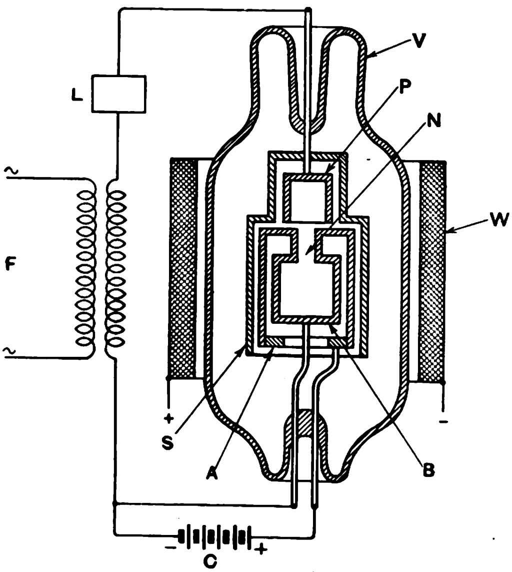


AN INTERESTING DISCHARGE TUBE.

(*Convention date* (*U.S.A.*), 5*th March*, 1925. *No.* 248,721.)

A very interesting form of discharge tube is described by the Raytheon Manufacturing Company and C. G. Smith in the above British Patent, which is very detailed and contains considerable information regarding the functioning of discharge tubes, particularly those containing an appreciable proportion of vapour. One form of tube is illustrated diagrammatically in the accompanying illustration. The glass envelope V is of cylindrical form and is situated within a winding W so that a longitudinal magnetic field can be applied to the electrode system contained within the bulb. The particular valve is a two electrode arrangement for rectifying purposes, and is provided with a cathode and an anode. The cathode consists of two concentric

cylinders *A* and *B* joined at their upper ends by a neck *N*. The anode *P* also consists of a cylinder closed at its upper end, the open end being situated above the neck *N*. A heat shield *S* is arranged in the manner indicated and is supported by the anode lead. The object of this is to confine the

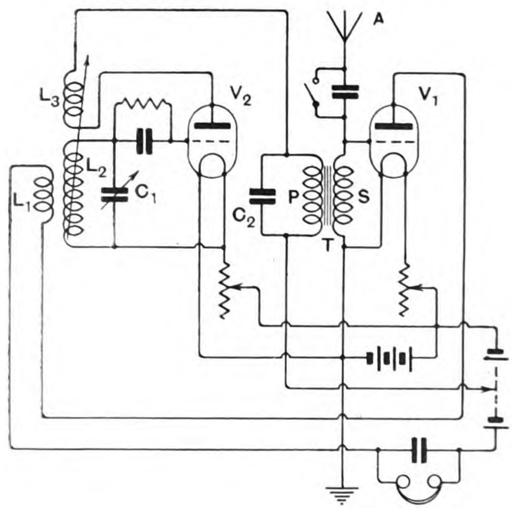


heat from the cathode, and the shield may be made of highly polished metal. The rectifier is shown connected to a source of supply from a transformer *F*, and is working into a load *L*. A battery *C* heats the cathode comprising the two cylinders. The valve is completely evacuated with the exception of a small amount of cæsium, or another alkali metal. This may be in the solid or vaporous form, but preferably a certain proportion should be in the solid form. The neck *N* is so constructed that the diameter is preferably less than the mean free path of the vapourised molecules outside the cathode, which, incidentally, is preferably made of tungsten. The connection of the battery *C* to the cathode should be such that the positive pole is connected to the outer cylinder. When the interior of the cathode is heated the vapour, particularly in the region of the neck, is ionised, and owing to potential drop down the neck the vapour is pumped into the cathode until a relatively high pressure is obtained therein. Under these conditions, that is the cathode being full of ionised alkali vapour under considerable pressure, an electronic discharge from the cathode through the neck to the interior of the anode is easily obtained at a comparatively low anode potential with respect to the cathode. There can be no reverse current because the interior of the anode does not contain highly ionised vapour under pressure. The space charge near the interior surface of the cylindrical anode is balanced out by the positive ions which are generated owing to the high temperature of the adjacent cathode, the two electrodes, of course, being enclosed together within the common shield *S*. A particular feature of this type of discharge tube lies in the fact that the rectifying property is not appreciably affected by the load to which it is connected, and accordingly a heavy load does not tend to prevent the device from rectifying properly. The object of the magnetic field produced by the windings *W* is to direct the electronic discharge from the cathode through the neck, and also to prevent it locating itself actually in or around the neck. Several other modifications are described in the specification, and also include tubes containing a control electrode, and those particularly interested in this type of discharge tube are referred to the specification for greater detail.

MINIMISING RADIATION.

(*Convention date* (*U.S.A.*), 18*th April*, 1925. *No.* 250,969.)

A receiving circuit particularly designed to minimise radiation from the aerial is described by S. Y. White in the above British Patent Specification. The invention really consists in connecting the aerial to the grid of a valve, the grid circuit of which contains no high-frequency reactance, so that the value of any radio-frequency potentials existing across the grid circuit will be comparatively small. This necessarily means that the particular valve will not function efficiently at radio frequencies but the valve is used as a low frequency amplifier and also as a means of transferring energy from the aerial to a detector valve. One method of accomplishing this is shown in the accompanying diagram.



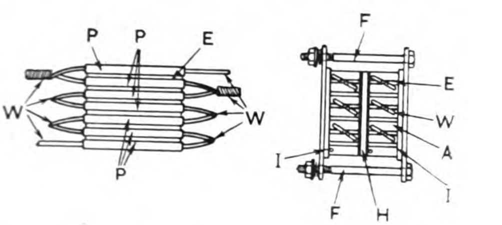
An aerial *A* is connected to the grid of a valve V_1, the grid circuit of which contains the secondary winding *S* of an intervalve transformer *T*. The anode circuit of the valve contains an inductance L_1 coupled to a tuned circuit $L_2 C_1$ connected to a detector valve V_2. The circuit $L_2 C_1$ is tuned

to the desired frequency of reception, while the anode circuit of the valve contains a reaction coil L_3. The anode circuit of the valve V_2 also contains the primary winding P of the intervalve transformer T, this winding being shunted by a capacity C_2 to by-pass any high frequency component. Radio-frequency potentials occurring across the aerial and earth will be transferred through the valve V_1 partly by capacity effect, and partly by a certain amount of amplification to the valve V_2, through the medium of the high frequency inductance L_1 in the anode circuit of the first valve. The oscillations induced into the tuned circuit $L_2 C_1$ will be rectified by the valve V_2. The rectified currents will be transferred by the intervalve transformer T to the grid circuit of the valve V_1, which will amplify them, the final currents being detected by the telephones, which are also included in the anode circuit of the valve V_1. The remainder of the circuit is quite straightforward, and will, therefore, not be described in detail. The specification also mentions several alternative arrangements and similar applications of the principles involved.

A THERMO-ELECTRIC GENERATOR.

(*Application date, 22nd March,* 1926. *No.* 265,519.)

A thermo-electric device is described by H. A. Roberts in the above British Patent Specification, the accompanying diagram illustrating the mode of construction. The elements of the device consist of alternate plates of positive and negative thermo-electric active metals P. The plates have cast into them wires W, the ends of which are twisted together so as to join the elements either in series or parallel, according to the relative voltages and currents which are required. The plates are separated from each other by washers E of asbestos

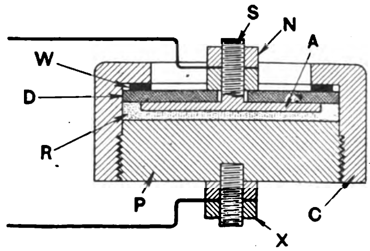


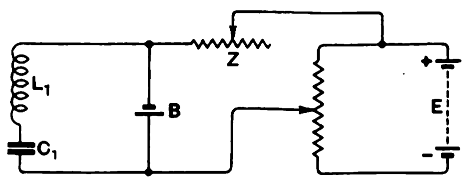
paper or similar heat-resisting insulating material. The assembly of plates is then clamped together in a framework F, which needs no description, the edges of the plates being insulated by strips I. The portion H represents a heater which may be an electric element, or it may be replaced by a series of gas flames.

AN INTERESTING DEVICE.

(*Application date, 9th October,* 1925. *No.* 265,052.)

L. Levy describes in the above British Patent an exceedingly interesting device which can be used as a rectifier or a generator or modulator of oscillations. The rectifier is of the aluminium and sulphide contact variety. The specification mentions that rectifiers consisting of aluminium in combination with cuprous sulphide have been used, but do not generally function satisfactorily after some time. This is supposed to be due to the fact that the cuprous sulphide becomes attached to the aluminium, and one then has cuprous sulphide in contact with cuprous sulphide, which does not rectify. This disadvantage is overcome by a method of construction disclosed in the





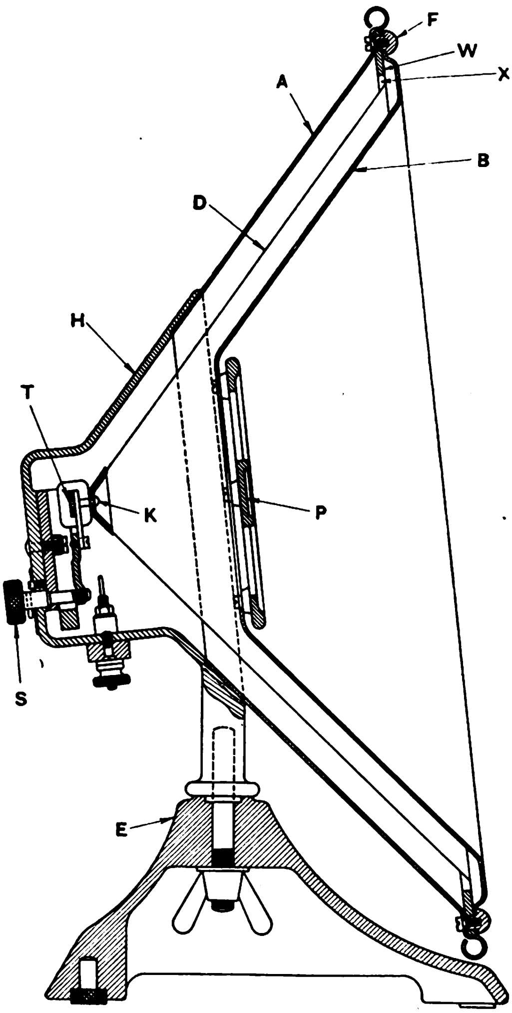
specification. The rectifier shown in the accompanying diagram comprises a copper or aluminium cup C provided with a screwed copper plug P. Inside the cup there is an insulating disc D of bakelite. Attached to the insulating disc D is an aluminium disc A located by means of a stud S and nuts N. The plug P is also provided with another stud and nuts shown at X. The space R is filled with the rectifying compound which is made in the following manner: Copper sulphide is first obtained by heating finely divided copper with sulphur, the two being arranged more or less in molecular proportion, but with a slight excess of sulphur. The resulting sulphide is then ground in a mortar until the powdered grains have diameters of the order of 0.2 of a millimeter. The powder is then sieved so as to remove any trace of metallic particles. The granular powder is then made into a paste by mixing it with a sulphuretting liquid such as ammonium hydro-sulphide. It is essential that the aluminium disc A, shown in the diagram, be chemically clean, and, particularly, free from oxide, and to ensure this the face and edge in contact with the sulphide paste is very carefully polished, this operation being carried out immediately before assembly in order to prevent the formation of oxide. Another essential feature of the device is that it must be gas tight. In order that gaseous pressure caused by the vapourisation of the liquid used for forming the paste may be produced inside the apparatus an annular washer W is included. It is stated that the increase of temperature caused by the current through the rectifier vapourises a

portion of the liquid, and this produces the necessary sulphuretting atmosphere. The specification describes various known arrangements of the rectifier for delivering high and low tension current to wireless receivers. One point of interest in connection with high voltage supply lies in the fact that it is preferable not to use a series of rectifying cells across the full voltage, but to supply each cell or small number of cells from a separate transformer winding. Another peculiarity of the device lies in the fact that it exhibits a negative resistance characteristic, thereby enabling it to be used as an oscillation generator. A suitable circuit is also shown in the diagram where a rectifier *B* in shunt with the tuned circuit L_1 C_1 is supplied through an impedance *Z* from a source of potential *E*. The arrangement, of course, is similar to the well-known Arc or Duddell circuit. Another modification of the invention lies in its use as a simple detector for wireless signals, when the sulphide arrangement is used in conjunction with a fine aluminium wire.

AN ENCLOSED CONE LOUD-SPEAKER.

(*Application date*, 28*th November*, 1925. *No.* 266,271.)

An enclosed type of loud-speaker is described by S. G. Brown in the above British Patent Specification, the accompanying diagram illustrating a suitable form of construction. The main features of the invention will be described in some detail. The conical diaphragm *D* is of paper or other light rigid material, and is connected at the base *A* to a reed type of drive or telephone movement *T* provided with an adjusting screw *S*. This type of movement has been previously described, and is no doubt familiar to readers. The diaphragm is enclosed between two metal cones. The back cone *A* is fixed to the housing *H*, which contains the telephone mechanism, which in turn is fixed to a supporting stand *E*. The cone *A* is actually provided with perforations, although this is not shown. The back cone *A* is attached at its periphery to the front cone *B*, the two being held together by bolts passed through their flanged edges at *F*. This junction also holds in position a ring *W* of wood or similar material. The periphery of the sound-emitting diaphragm *D* is attached to this ring *W* by means of very thin tissue paper or similar material at *X*. Referring again to the front cone, this is truncated and provided with a perforated circular disc *P*, through which the sound from the diaphragm can pass. The chief object of the invention is to secure a light and free method of supporting the diaphragm, and, at the same time, protect it from mechanical injury.



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EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. JUNE, 1927. No. 45.

Editorial.

The Eclipse.

ON the morning of 29th June a total eclipse of the sun will occur and will be visible in England. Such an event has not occurred since the eighteenth century and will not occur again until the last year of the present century. To most people in this country it will appeal as a unique opportunity—given favourable weather conditions—of watching a rare natural phenomenon, but to scientists it will appeal in many different ways, depending on the branch of science in which they are specially interested. To wireless experimentalists it offers an opportunity of making measurements of the strength or direction of signals with a view to determining any special variation due to the eclipse. It is impossible to say exactly what measurements it would be best to make, but there is one thing which should be emphasised above all else and that is, that unless the greatest care be taken to obtain accuracy and reliability, the results obtained will be worthless.

It will be necessary for each observer to decide on which transmitting station he will concentrate his attention. Arrangements are being made for certain of the broadcasting stations to send out steady signals for the purpose. Particulars of some of the observation work to be carried out by the Radio Research Board under the direction of Professor E. V. Appleton, F.R.S., are published on page 381. These stations will send out the signals in exactly the same way on several days before and after the 29th and it will be essential to make the measurements on these days as well as on the day of the eclipse, as it will only be by comparison of this kind that any effect of the eclipse will be detected.

In deciding the transmitting station on which he will concentrate his attention, the observer will be guided by his position with respect to the track of the shadow, but he must not be misled by maps showing the shadow track sweeping across the country from North Wales to Sunderland, for these maps refer to the shadow on the ground. If the eclipse has any effect on wireless signals it will be due to changes produced in the upper atmosphere and the shadow which interests the wireless observer is that cast on the ionised layer at a height of about 50 miles. As the eclipse occurs so soon after sunrise the sun's rays make a small angle with the surface of the earth and will therefore pass through the ionised layer at a point about 150 miles south-east of the point where they strike the ground. Hence for wireless purposes the track of the shadow across the country lies perhaps 100 miles to the south of the observational track, the exact position depending on the height assumed for the ionised layer. Wireless observers in Yorkshire and Lancashire are therefore well to the north of the shadow track which will have any effect on signal strength.

The Exact and Precise Measurement of Wavelength in Radio Transmitting Stations.

By RAYMOND BRAILLARD Engineer A. & M., E.S.E., Advisory Engineer of Radio-Belgique, President of the Technical Commission of the Union Internationale de Radiophonie; and EDMOND DIVOIRE, Engineer A.I.Br., in charge of classes at Brussels University, Secretary of the Technical Commission of the Union Internationale de Radiophonie.

Part A.—THE BROADCAST PROBLEM.

General Considerations.

RECEPTION of broadcast transmissions of good quality, using a properly designed set, may be more or less seriously affected by four main classes of stray radiations—

(*a*) Strays of natural origin, generally called "atmospherics";

(*b*) Strays of an industrial origin: induction caused by tramways, electric trains, lifts, X-ray appliances, luminous signs, telegraphic equipment, high power transmission lines, electric motors, etc.;

(*c*) Stray radiations from neighbouring receiving sets badly adjusted;

(*d*) Jamming by other transmissions—on the same or on neighbouring wavelengths or by harmonics of long wave stations.

We will not deal, in the course of the present study, with the three first causes of reception trouble, forming as they do the subject of constant research on the part of technical experts of all lands, but will confine our attention to the fourth.*

Radio-Electric Interferences.

Incessant increases in the number and power of radio-electric stations involve, by way of consequence, an increase in reception interference capable of seriously compromising the legitimate development of wireless applications.

It is necessary to recognise the fact that the law "Lex talionis" which has, for a long time, worked as a moderating agent, shows itself definitively as being inoperative because it conduces, in the absence of any rational international organisation of wireless, to a chase after power.

The last international meeting* regulating the conditions of the use of wireless in various domains dates back, as a matter of fact, to 1912.

The forthcoming universal congress, which is to meet at Washington in October, 1927, and of which the heavy task of organisation is incumbent on the American Government, has been adjourned from year to year for various reasons.

Owing to these adjournments the prodigious evolution of broadcasting and the multiplication of telegraphic, naval, aircraft and meteorological services, etc., have ended up by creating a state of things such that the responsible technical experts consider with real anxiety the announcement of the erection of other new transmitting stations as the prospect of a new source of interference.

International Agreements for Wavelength Allotment.

While waiting for the new organisation, which has been promised us at Washington, and of which the results will not be perhaps either so efficacious or so rapid as one is pleased to hope,† the technical experts have sought, under the urge of necessity, to work in as well as possible within each radio-electric branch, wavelengths which have been occupied *de jure* and *de facto* in order to derive therefrom the best possible benefit.

It is this which gave rise to an organisation

* The Union Internationale de Radiophonie in particular is actively occupied in the study of the problem of strays of industrial origin, under its twofold technical and juridical aspects.

* The London meeting.

† As a matter of fact, months and even years have passed between the closing of such meetings and the date of putting into force, by the various interested Governments, the resolutions adopted. Furthermore, the rules admitted or enacted, very often at the end of numerous compromises, are not always suitably rigorous to bring about a definite remedy for the defects which one desired to avoid.

such as the Union Internationale de Radiophonie, whose original purpose, since considerably enlarged in the juridical and artistic domains, was to find a remedy for growing interference which was compromising the development of European broadcasting. As we have said, the London Convention, which regulated wireless from the international point of view, dates from 1912. The case of broadcasting has not been provided for, and no international agreement has correlated national regulations of various countries which may have been contradictory or inadequate. The Union Internationale de Radiophonie, created in March, 1925, groups together at Geneva the majority of European broadcasting organisations.

After a series of studies and tests carried out by a technical committee appointed to this end* a first "European" plan for allotment of wavelengths between 200 and 600 metres was adopted at Geneva in March, 1926, and applied to the great majority of European broadcasting stations on the 15th November of the same year. The result obtained was remarkable in its entity and would have been complete were it not for several causes of trouble arising from stations which have not rallied to the plan, or which are working under defective technical conditions.

A similar allotment plan, dealing with long wave stations, is now being studied.†

* This Committee consists of :—

President: M. Raymond Braillard, Engineer A. and M.—E.S.E.—Advisory Engineer of Radio-Belgique (Brussels).

Members: M. Cesare Bacchini, Administrator of the Unione Radiofonica Italiana (Milan). Capt. P. P. Eckersley, Chief Engineer of the B.B.C. (London). M. Pierre Gendron, Technical Director of *Petit Parisien*. Dr. Harbich, Director of P.T.T. (Reichs Rundfunk, Berlin). M. Siffer Lemoine, Engineer at the Direction Générale des P.T.T. Suédois (Stockholm). M. Ernst Steinbach, Engineer Radio E.S.E.; Chief Advisor of Postes et Télégraphes (*Radio Journal*), Prague. Dr. B. van der Pol, Director of the Research Laboratory, Philips (Eindhoven).

Secretary: M. Edmond Divoire, Engineer, Radio E.S.E., in charge of classes at University of Brussels.

† International Conference of Broadcasting Engineers organised at Brussels, 28th and 29th of January, 1927, by the Technical Committee of the U.I.R.

Technical Qualifications which Broadcasting Stations must Satisfy.

All tests for regulating wavelengths with a view to suppressing interference will be illusory if broadcasting stations do not satisfy the three following conditions :—

1. The length, or rather the frequency of wave emitted, should correspond exactly with nominal wavelength allotted.

2. The emitted wave should remain stable; no matter what kind of manipulation or modulation be adopted.

3. The emitted wave must be free from appreciable harmonics.

The strict observance of these conditions is indispensable for safeguarding wireless progress. It nevertheless does not appear, on the whole, that builders of broadcasting stations have sufficiently borne this in mind, as can easily be seen by listening to the majority of radio-telegraphic or radiophonic transmissions.

The accuracy of the frequency of the emitted wave depends mainly on the technical value of the wavemeter used to regulate a station.

The stability and suppression of harmonics are obtained, thanks to the aid of equipment which is well known to-day, and which we will not deal with in the course of the present study.

It should be noted, however, that a good wavemeter at a broadcasting station not only enables one to obtain an accurate adjustment of wavelength, but furthermore to control its stability.

The Problem of Wavemeters.

The exact and precise measurement of wavelengths constitutes a delicate problem which in the minds of many technical experts appertains solely to the laboratory.

In the very great majority of stations, we find, as a matter of fact, wavemeters which offer none of the characteristics suitable for obtaining the accuracy and precision desired. Very often these appliances are of an obsolete model, and their present standardisation corresponds only very roughly with their initial standardisation, which in itself afforded only a very approximate accuracy.

Thus, it is not infrequent to find that the wave transmitted by a telegraph or telephone

station differs by 3 to 4 per cent. or even more from the nominal wave appearing in official lists.

As we have said above, the present situation will no longer allow of such a degree of inaccuracy, which some years ago did not present any inconvenience.

Let us consider the class of radiophonic transmitters :—

It has been found necessary to observe separation of 10 kilocycles between the frequencies of stations on neighbouring wavelengths, in order to avoid, on one hand, the heterodyning of modulation bands, and on the other hand the production of a permanent audible note arising from interference on carrier waves by the well-known heterodyne effect.

Now in the waveband of 200 to 600 metres a margin of 10 kilocycles between frequencies corresponds to a comparative margin as follows :—

2 per cent. in wavelength for a wave of 600 metres.

1 per cent. in wavelength for a wave of 300 metres.

0.66 per cent. in wavelength for a wave of 200 metres.

It is, therefore, very obvious that an accurate wavemeter, affording an accuracy of the order of 1 per cent., which is normally considered as remarkable for commercial sets, would be quite inadequate, seeing that its absolute error would correspond to a margin of frequencies of two stations on neighbouring wavelengths.

It is for these reasons that the Technical Committee of the Union Internationale de Radiophonie foresaw, as a condition indispensable to the success of all international wavelength allotment plans, the necessity of keeping each station on its normal wave with an accuracy achieving the order of several ten thousandths.

There is no doubt that this condition, which might at first sight appear draconian, will be imposed with a more or less brief delay in all branches of the applications of radio-electricity.

Faults of Ordinary Wavemeters.

The best ordinary wavemeters always show the following faults :—

1. Their waveband is too extensive, as manufacturers seek to turn out sets which are more or less universal and as such can adapt themselves to no matter what station. The result is that the reading of wavelengths offers a great degree of inaccuracy, especially at the beginning of the scale, for condensers are generally of the semi-circular moving plate type. Thus, for instance, we frequently find that the wavelength band of 200 to 600 metres is represented by 100° or less on the scale. Errors in reading may, therefore, easily reach or exceed the value of the margin separating two neighbouring stations.

2. Standardisation is not constant. This is due to mechanical deformations in the constituent elements. Especially in variable condensers with parallel blades and great capacity, the wearing away of pivots and stops involves comparatively important variations in the air gap and consequently in capacity. We have often found that good sets had, after several months of use, suffered variations in standardisation rising to 1, 2 or even 3 per cent., which one had to attribute mainly to variations in condenser capacity.

3. Damping is generally very high because in sets with an extensive band the multiplication of control or working parts, the grouping together of constituent elements of the oscillating circuit within a reduced space, the abundance of connections, etc., involve important losses. The result is on the one hand a greater inaccuracy in ascertaining the point of resonance and on the other hand the necessity for tight coupling between the wavemeter and the transmitter, which may give rise to a temporarily varying of wave during measurement when dealing with low power stations.

4. The appliances are not protected against electrostatic effects. The approach of the hand, head or body of operator during measurement may also cause large errors in the value of such measurement.

The Solution of the Technical Committee of the U.I.R.

After having first prescribed the general restandardisation of wavemeters in service in all stations in a single laboratory provided with a single frequency standard, the Technical Committee of the U.I.R. turned down this solution on account of its uncertainty.

Another solution which was at first sight very alluring consisted in using resonant piezo-electrical quartz crystals, carefully calibrated on stationary waves.

Such appliances, generally of very great accuracy, are in use in several important stations, especially in Germany. Unhappily, their use is fairly delicate, and they suit only very modern stations, with a very stable transmission and provided with a selected technical staff; but their use could not be generalised at the present without risk of abuses.

Finally, the Technical Committee of the U.I.R. decided on the following scheme :—

(*a*) To study a new wavemeter, accurate, precise, stable, covering a very narrow frequency band around the operating frequencies and to equip each broadcasting station with one.

(*b*) To mass produce these wavemeters with a view to reducing in so far as possible the cost price so as to permit of their being widely distributed.

(*c*) To standardise all wavemeters according to the most modern methods of absolute frequency measurement in one and the same laboratory equipped with a single frequency standard.

These various operations were carried out at Brussels in the wireless laboratory of the University under the care of the authors and in complete and constant agreement with all members of the Technical Committee of the U.I.R.

Starting in August, 1926, they were carried through very rapidly and in December of the same year more than 60 European stations, amongst them the most important, were already permanently controlled by these sets, which we are going to describe more in detail.

Part B.—DESCRIPTION OF WAVEMETER.*

Conditions to be Realised.

In the construction of the wavemeter, we have imposed on ourselves at the outset the three following conditions :—

(*a*) To reach an accuracy of reading as high as possible. This will mean, on the one hand, a careful study of the different elements, so as to lower damping to a minimum in circuits, and on the other hand, a reduction of the waveband which the instrument will cover.

(*b*) To get a perfect constancy of standardisation, and to this end, to build each instrument particularly robustly and rigidly so as to avoid all ulterior geometrical deformation involving a modification of the electrical characteristics of the instrument.

(*c*) To limit the cost of manufacture to a comparatively low value, in order to enable, no matter what broadcasting station, to acquire the wavemeter; it was therefore necessary to eliminate all expensive meters, and generally to have recourse to industrial processes of mass production without compromising indispensable accuracy in manufacture.

The three above considerations lead us to work out a combination comprising :—

1. A resonant circuit reduced to its essential elements, viz., a fixed inductance and a big fixed and a small variable condenser, mounted in parallel (see Fig. 1)

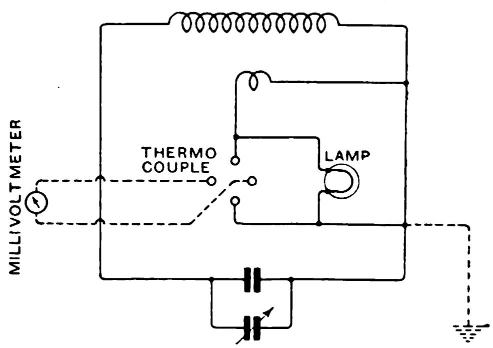

Fig. 1.

M the capacity of this latter being calculated so as to ensure a total band of frequencies equal to a small percentage of the total value.

2. An indicator circuit loosely coupled up to the resonant circuit and consisting essentially of a simple incandescent lamp as a measuring instrument.

Make-up of Instrument.*

As we have shown above, we have deliberately abandoned the principles on which

* Registered Patent.

* See photo, Fig. 2.

instruments of the kind ordinarily are based, such as doing away with important metallic masses, general use of ebonite and other insulators, etc.

On the contrary, we have adopted, after study, a metallic construction very robust wherever possible: parts of well finished cast metal, solidly fixed to a very thick aluminium panel — the use of insulating unwanted electrostatic and other effects, due to the presence of observer, which effect might alter this standardisation.

Lastly, we had recourse, as much as possible, to cast metal so as to reduce ulterior deformations resulting from molecular action. This is difficult to avoid when using welded metal, such as plates, cylinders, etc.

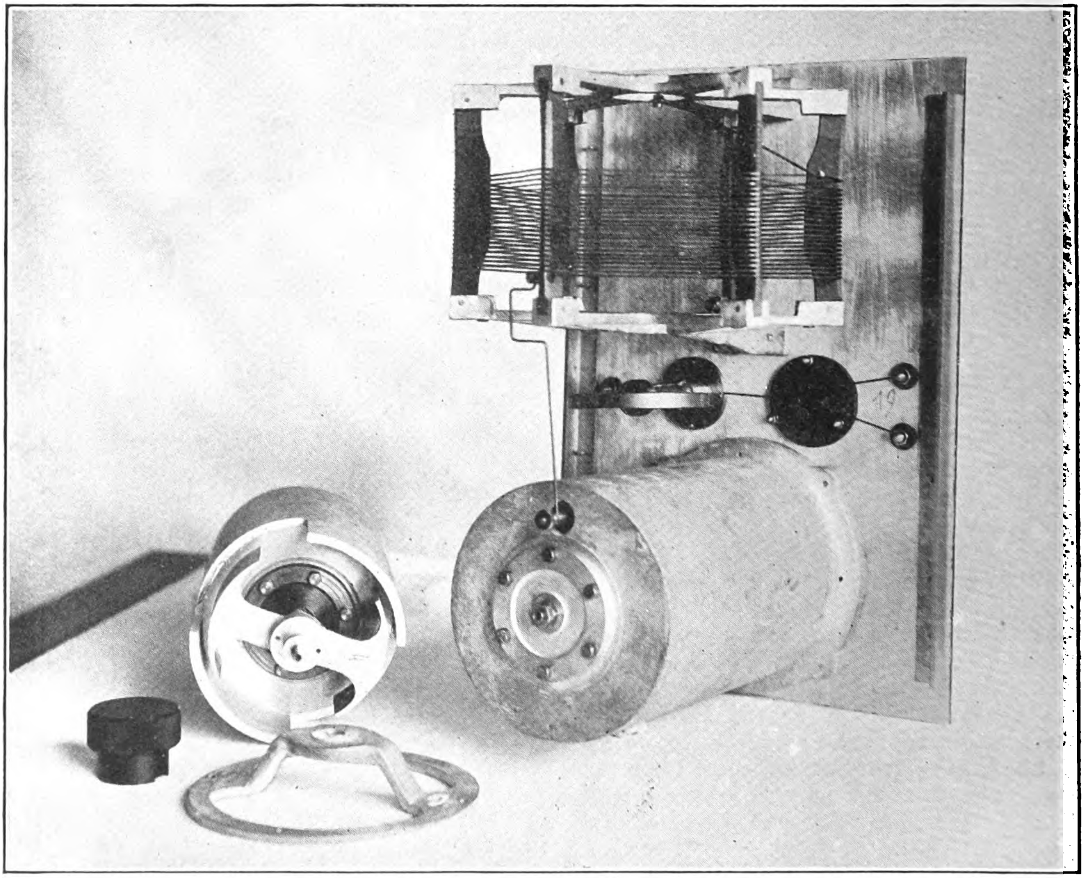

Fig. 2.

material being strictly limited where it was indispensable. (Further, the adoption of a very narrow waveband: about 30 kilocycles).

The advantages resulting from this particular construction are, first of all, the rigidity and indeformability of the separate parts, and thence, constancy of standardisation; next an almost radical way of avoiding

Condensers.

We have seen that the condenser is made up of :—

(*a*) a fixed condenser;

(*b*) a variable condenser, covering a frequency band slightly above 30 kilocycles.

It is easy to calculate that the variable

section of the capacity is comprised between 5 per cent. and 11 per cent. of the total capacity for waves between 200 and 600 metres. This considerably reduces errors arising from mechanical deformations of moving parts.

To reduce damping, it was thought to be essential to use air dielectric condensers.

After studying the matter, we rejected the multiple parallel plate condensers of the well-known type, to adopt condensers made up in the main by two concentric cylinders.

It would be interesting to develop mathematically the reasons.

Let us first consider a condenser element made up of three parallel plates, separated by an air gap equal to C, the central plate forming one side, and the external plates the other side, and let us find the capacity variation resulting by shifting E, the central plate, towards one of the other plates (see Fig. 3 (a)).

The initial capacity per square centimetre of surface is :—

$$C_0 = \frac{1}{4\pi} \cdot \frac{2}{C}$$

After displacement it becomes :—

$$C_1 \cdot = \frac{1}{4\pi(e+\epsilon)} + \frac{1}{4\pi(e-\epsilon)} = \frac{1}{4\pi} \cdot \frac{2e}{(e^2-\epsilon^2)}$$

Whence

$$\Delta C = C_1 - C_0 = \frac{1}{4\pi}\left(\frac{2e}{e^2-\epsilon^2} - \frac{2}{e}\right)$$

$$= \frac{1}{4\pi} - \frac{2}{e} - \frac{\epsilon^2}{e^2-\epsilon^2}$$

We easily derive

$$\frac{\Delta C}{C_0} = \frac{\epsilon^2}{e^2-\epsilon^2}$$

and as ϵ is small compared with e

$$\frac{\Delta C}{C_0} = \frac{\epsilon^2}{e^2} \quad \ldots \quad \ldots \quad (1)$$

The effect of compensation is obvious, seeing that a small variation of air gap corresponds to a variation $(\epsilon/e)^2$ of capacity and $\frac{1}{2}(\epsilon/e)^2$ of frequency.

Thus, the variation of 1/100 of air gap would correspond to a variation of 1/10,000 of capacity, or 1/20,000 of the frequency.

But in practice it is different, because it is extremely difficult to construct such a condenser with an initial air gap e constant.

We can find, as a matter of fact, that the *mean value* of this air gap is equal to e, but there are always two different air gaps, e_1 and e_2.

$$e_1 = e\,(1 + K)$$
$$e_2 = e\,(1 - K)$$
$$e_1 + e_2 = 2e$$

Under these conditions the initial capacity is :—

$$C_0 = \frac{1}{4\pi} \cdot \frac{1}{1-K^2} \cdot \frac{2}{e}$$

A further displacement of central plate gives, taking the most unfavourable case

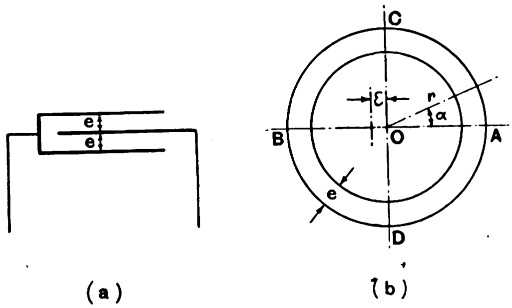

Fig. 3.

for which a difference of air gap is accentuated,

$$e_1 = \frac{1}{4\pi} \cdot \frac{1}{1-K^2} \cdot \frac{2(e+K\epsilon)}{e^2-\epsilon^2}$$

We thus easily derive :—

$$\frac{\Delta C}{C_0} = \frac{K\frac{\epsilon}{e} + \left(\frac{\epsilon}{e}\right)^2}{1 - \left(\frac{\epsilon}{e}\right)^2}$$

and as $(\epsilon/e)^2$ is small compared with 1

$$\frac{\Delta C}{C_0} = K\frac{\epsilon}{e} + \left(\frac{\epsilon}{e}\right)^2 \quad \ldots \quad \ldots \quad (2)$$

Comparing this formula with the corresponding formula in the initial theoretical case, we at once see that the inevitable initial mechanical imperfection leads to the introduction of a term of variation of the first degree which may become very quickly preponderant when K increases.

Taking K=0.10, which is very difficult to realise industrially, we find ϵ/e=1/100 :

$$\frac{\Delta C}{C_0} = 0.1 \times \frac{1}{100} + \frac{1}{10{,}000} = \frac{11}{10{,}000}$$

Variation, therefore, is eleven times greater than in the theoretical case corresponding to air gaps strictly equal in construction.

The difficulty of keeping equal air gaps increases, moreover, rapidly when we increase the number of plates and it becomes almost insurmountable when we desire to realise variable condensers rotating on this principle.

On the other hand, the welded plates usually employed are liable to gradual deformations, which are nevertheless important and are due to variation in molecular stresses in the metal even in the absence of major temperature variations.

The foregoing considerations alone explain all the faults which have up till now been encountered in the construction of wavemeters, no matter how much care be given to the mechanical design of variable or fixed condensers with multiple blades used in industrial equipment.

They explain moreover the extent to which the standardisation of wavemeters carried out on receiving sets comprising such condensers is unreliable.

We will now consider a condenser formed of two concentric cylinders, separated by a constant air gap, small in regard to the radius (see Fig. 3(b)).

The capacity per unit of length of cylinder is equal to $1/2e$.

Let us now seek, as formerly, the comparative variation of capacity produced by a displacement ε of one of the armatures, ε being small in comparison with e. In A, the gap becomes $e+\varepsilon$. In B it is reduced to $e-\varepsilon$. In C and D the gap is constant. Taking CA as a basis we may admit that the air gap varies according to the law:—

$$e+\varepsilon \cos \alpha$$

Let us seek the value of capacity of a semi-cylinder ACB.

The initial value is:—

$$C_0=\varepsilon/4e$$

The new value becomes:—

$$C_1=\frac{1}{4\pi}\int_0^\pi\frac{\partial\alpha}{e+\varepsilon\cos\alpha}$$

being greater than C_0

the general integral is given by

$$\int\frac{\partial\alpha}{e+\varepsilon\cos\alpha}=\frac{2}{\sqrt{e^2-\varepsilon^2}}\ \text{arc tan}\ \frac{\sqrt{e-\varepsilon}\tan\frac{\alpha}{2}}{\sqrt{e+\varepsilon}}$$

Proceeding to limits we find

$$C_1=\varepsilon/4\cdot\frac{1}{\sqrt{e^2-\varepsilon^2}}$$

whence

$$C_1-C_0=\varepsilon/4\left(\frac{1}{\sqrt{e^2-\varepsilon^2}}-\frac{1}{e}\right)$$

We derive

$$\frac{\Delta C}{C_0}=\frac{e-\sqrt{e^2-\varepsilon^2}}{\sqrt{e^2-\varepsilon^2}}$$

or after reduction and allowing for $(\varepsilon/e)^2$ being small in comparison with 1:—

$$\frac{\Delta C}{C_0}=\frac{1}{2}\left(\frac{\varepsilon}{e}\right)^2 \quad \cdots \quad \cdots \quad (3)$$

In comparing this value with the corresponding value given in (1) for parallel plate condensers, we see that the capacity variation with equal air gap and displacement is twice as small.

We may assume that in construction an eccentricity existed from the start.

Without developing the calculation, let us point out that in this case we find:—

$$\frac{\Delta C}{C_0}=K\frac{\varepsilon}{e}+\frac{1}{2}\left(\frac{\varepsilon}{2}\right)^2$$

a formula which it is well to compare with (3).

To sum up, we see that in all cases the subsequent accidental variation of the capacity depends principally on the accuracy of initial performance, that is to say, on the value of K. Now it is very easy to attain an extremely low value for the term K with well made and perfectly concentric cylinders. The advantage of cylindrical condensers is, therefore, considerable from the standpoint of stability of capacity value. If we take care, moreover, to form the cylindrical plates out of cast and turned pieces of metal, and not out of drawn tubes, we avoid all deformations due to internal molecular tension.

The above considerations lead us to design wavemeters in the following manner:—

(*a*) *Condensers.*—Fixed and variable condensers are formed in one and the same organ, the plates being concentric cylinders mounted on a fixed axis and held at both ends by conical bushes. The external cylinder forming a cover is joined to the case while the internal cylinder is insulated from the axis

at both ends by means of extremely thin pieces of ebonite moulded in the form of opposing cones at the base. This special arrangement ensures perfect rigidity of insulating material and at the same time gives conditions suitable for perfect insulation, *i.e.*, minimum section, minimum volume and maximum length of leakage path. The moving electrodes are supported on the same axis, centring being ensured by a truncated conical bush. The moving electrodes comprise two quadrants of cylinders spaced 180° apart, and have the same polarity as the mass of the external cylinder. Variations of capacity are given by a movement of these electrodes in front of two other quadrants, which are fixed on the shell, being in fact prolongations of the internal cylinder which is insulated and therefore of inverse polarity (see Fig. 2).

The above method of condenser design not only assures a unit of great robustness, but also has for its object the securing of accurate mounting of the electrodes with respect to one another, and furthermore reduces to an insignificant value not only risk of eccentricity and accidental deformation, but also that of initial eccentric mounting.

(*b*) *Inductance.*—The inductance is formed by a coil of bare copper wire supported by six insulating strips forming the facets of a hexagonal prism. The two bases are formed by aluminium supports in the form of six branch stars and rendered perfectly rigid by stays.

The diameter of these bases is constant for all models of wavemeters; the pitch of winding and section of wire have been specially studied so as to reduce high frequency resistance.

For the insulating material chosen for the strips, measurement showed that its choice was of little account in regard to loss. As a matter of fact, in such a coil the copper loss was preponderant compared with dielectric losses.

Nevertheless, the necessity of keeping a strictly indeformable winding has led us after tests with strips of ebonite and bakelite of the best quality to consider the use of pyrex glass or fused quartz.

We will revert later on to the values of resistance on which we have decided.

(*c*) *The indicator circuit* is made of a single turn of thick brass strip which is perfectly rigid and is mounted on a brass base. The loop is directly connected to the resonance indicator which is either a small incandescent lamp of the 3.5-volt type, or a thermoelectric couple of the Allochio and Bacchini type used in conjunction with a D.C. millivoltmeter.

Obviously both systems of measurement cannot be used simultaneously.

Study of Instrument's Characteristics.

A. Inductance and Capacity.

The first question which arose was to fix the value of the ratio Inductance/Capacity to be adopted for the series of wavemeters that had to measure the wavelengths in the 200 to 600 metres waveband.

In defining this we were at first guided by considerations of the accuracy to be obtained. This ratio fixes in fact the circuit decrement for each wavelength, and consequently the degree of accuracy.

What was the problem?

In the present case it was to measure between 200 and 600 metres a series of frequency intervals of 10 kilocycles each, with as much accuracy as possible, involving an error lower than one kilocycle.

The result is that for a 600-metre wavelength (500 kilocycles) this accuracy should be at least 2/1,000, while for 200 metres (1,500 kilocycles) it should be 0.66/1,000.

Consequently, the problem was not to obtain a constant value of comparative accuracy over the whole waveband, but really a constant value of absolute frequency accuracy.

Which in other words means that it would be necessary to make the condition Δf=constant for all decrements.

Now, we have δ appreciably proportional to $\Delta f/f$.

It was therefore necessary to get

$$\delta = K \frac{1}{f}$$

Or, again, by replacing δ by its value $\frac{R}{2L} \cdot \frac{1}{f}$

$$= \frac{R}{2L} \cdot \frac{1}{f} = K \frac{1}{f}$$

Giving therefore, $R/2L$ the constant for all instruments.

Such was the desideratum; but was it possible?

Let us roughly estimate R and L as a unction of the number of turns of inductance and the frequency, the condenser resistance being regarded as negligible compared with that of the inductance (which is nearly true in our case).

In a coil of the type adopted we may assume that the H.F. resistance is proportional to the D.C. resistance and to the square root of the frequency

$$R_{HF} = KR_{DC}\sqrt{f} = K'n\sqrt{f}$$

(n. representing the number of turns).

On the other hand, our experiments have shown that we got the ratio $L = K'n^2$ approximately.

Whence, finally, the condition

$$R/2L = \text{constant}$$

works out at

$$L = K \times f = K'/\lambda$$

The inductance, therefore, instead of increasing with wavelength, should diminish.

It is easy to see that this condition would rapidly lead to inadmissible capacity values for the two extremities of the waveband required.

We have, therefore, confined ourselves to a *comparatively* constant accuracy taking care that this accuracy should suffice for the most unfavourable case, that is to say, for the shortest waves.

This meant that the condition

$$\delta = \frac{R}{2L} \cdot \frac{1}{f} = \text{constant}$$

was realised, or, taking into consideration once more the above approximations in the evaluation of R and L, the adoption of a constant ratio L/C for the different instruments.

Experience shows, as a matter of fact, subsequently, that in this way the decrement of different wavemeters falls regularly between 0.016 and 0.018 for the ratio $L/C = 0.5$ *circa* (L expressed in microhenries and C in microfarads).

(To be concluded.)

Slope Inductance.*

A Note on the Effective Inductance of Iron-Cored Chokes or Transformers.

By C. R. Cosens, M.A.

THE *Inductance* of an air-core choke is a constant quantity, independent of the current through the choke, and it may be defined as the "flux-turns per unit current."

It is well known that the inductance of a choke having a closed, or nearly closed, iron core is not a constant,† because the permeability of the iron varies with the flux-density; but it is not generally realised that the extent of this variation may be as much as ten or twenty to one.

A.C. Inductance and Slope Inductance.

The quantity $\frac{\text{“Total flux-turns”}}{\text{Current}}$ as calculated from the reactance of the choke to a sine-wave A.C. current will be referred to as the *A.C. Inductance.* (This is the quantity which is required for ordinary A.C. work, other than wireless.)

The quantity $\frac{\text{“Change of flux-turns”}}{\text{Change of current}}$ (where the change of current is small, and is superimposed on a relatively large D.C. current through the windings), will be referred to as the *Slope-inductance.* This is the effective inductance of the choke when used in an amplifier where the windings carry a steady D.C. anode current upon which is superimposed a relatively small A.C. component, referred to as the "Signal current."

Frequency adopted for Tests.

In pursuance of the principle of measuring one thing at a time, it is desirable to eliminate, as far as possible, the effects of the self-capacity of the coil windings, this points to the use of a comparatively low frequency for the test. The commercial 90 cycle A.C. supply was therefore used, which is practically convenient.

Test of A.C. Inductance.

The impedance Z of the choke is easily measured by noting the currents passed with various applied alternating potentials. In practice the current-measuring device is conveniently an adjustable non-inductive rheostat across which a Moullin voltmeter is connected.

If R is the resistance of the adjustable rheostat, and r the effective A.C. resistance of the choke (including iron losses), the reactance X of the choke is then obtained from

$$Z^2 = X^2 + (R + r)^2 \quad .. \quad (1)$$

In practice, we do not know the effective resistance r, but fortunately it will be found that if we assume the iron losses are of the same order as the copper losses, we can neglect r altogether as small compared with X. (For proof see Appendix I.)

We have, then, approximately,

$$X = \sqrt{Z^2 - R^2} \quad .. \quad (1A)$$

and if f be the frequency of supply,

$$L = X/2\pi f \quad .. \quad .. \quad (2)$$

A.C. Inductance of Commercial Choke.

The results of such a test of A.C. inductance of a commercial choke of well-known make are plotted (on semi-logarithmic paper) in Fig. 1, against the A.C. current through the choke (R.M.S. value). Strictly speaking, there is a source of error here, in that if the applied E.M.F. is sinusoidal the current will show a pronounced third harmonic, but the test will still be suitable for comparison of different chokes; the error is probably small, as the effect of the adjustable resistance in series with the choke is to reduce the error.

* M.S. received April, 1926.

† If the iron core has an air-gap so large that the reluctance of the gap is much greater than that of the iron part of the magnetic circuit (a few millimetres may suffice where the iron is worked at a high permeability) the inductance is for practical purposes nearly constant, within a few per cent.

In the actual test the current was carried up to 12 milliamperes; the P.D. across the choke was then about 500 volts R.M.S. (a peak value of at least 700 volts). It speaks well for the insulation of the choke that it stood up to this for over five minutes without any sign of breakdown.

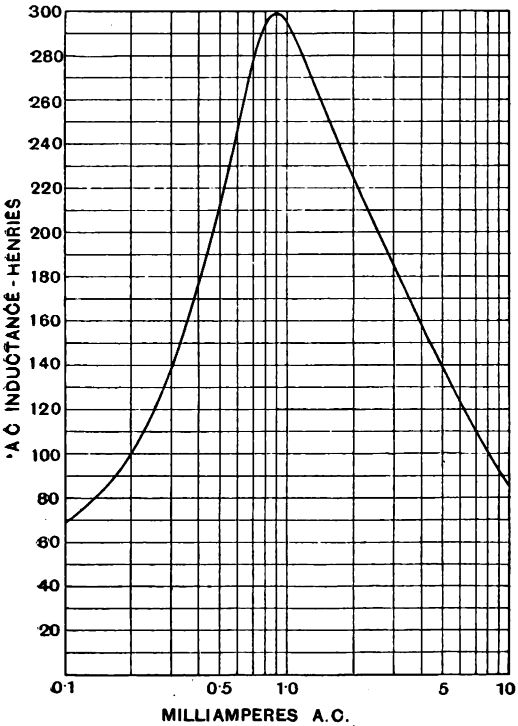

Fig. 1.

An inspection of the curve of Fig. 1 shows that the A.C. inductance is of the order of 60 henries for a very small current (found by extrapolation from a curve drawn on ordinary, not semi-log., paper), rising to 300 henries for a current of about 1 milliamp of A.C. (This is not of much practical use, as it needs a P.D. of about 160 volts across the choke to drive 1 milliamp through the winding, even at so low a frequency as 90 cycles.)

Above 1 milliamp A.C. the inductance drops, until at about 14 milliamps it becomes about the original 60 henries; and if a larger A.C. current could be passed without damaging windings and insulation, the inductance would presumably decrease indefinitely.

It will be noticed that the shape of the curve of Fig. 1 is similar to that of the permeability-curve of iron, in actual fact this is exactly what it is; with a knowledge of the number of turns on the winding and the dimensions of the core we could draw new scales on the axes to show the μH relationship for the iron. Incidentally this is a method of measuring permeability with a single winding only on the core. (For proof see Appendix II.)

Conditions of Operation of a Choke in an actual Amplifier.

The results of the test just given do not show anything like the actual effective inductance of the choke when employed in the anode circuit of a valve, for in such a position we have a small A.C. "signal E.M.F.," of a few volts at most, across the choke, and superimposed on the small A.C. "signal current" due to this E.M.F. a comparatively large D.C. current, the anode current of the valve.

In this connection, it may be noted that the signal E.M.F. on the grid of the last valve of an amplifier adjusted to give comfortable volume on a medium-sized loud-speaker, is of the order of 5 volts R.M.S. This was measured on the tuning-note of 5XX (corresponding, the B.B.C. state, to about 80 per cent. modulation), the measurement being made with a Moullin voltmeter.

In order to obtain comparative results, it was decided to use a constant signal E.M.F. of 3 volts R.M.S. at 90 cycles; the "slope-inductance" of the choke was then calculated as before, from the impedance, but with different D.C. currents flowing in the windings. This to some extent reproduces the average conditions of operation in an actual amplifier.

Connections for Test of Slope-Inductance.

The principle of the test is as follows: If the choke is connected in series with a non-inductive rheostat, so adjusted that the A.C. potential difference across the rheostat is equal to that across the choke, the impedance of the choke will then be numerically equal to the resistance of the rheostat, thus saving calculation. To do this we require two things. Firstly, we must supply the choke and rheostat with both D.C. and A.C. without the supplies mutually interfering,

and so that the D.C. current can be accurately measured. Secondly we require a means of measuring the small A.C. potentials across the choke and rheostat, which shall be unaffected by the comparatively large D.C. potentials present, and which shall take no appreciable current from the circuit. The latter requirements are admirably met by a Moullin voltmeter of the grid-rectifying type, provided that the insulation resistance of the grid-condenser is sensibly infinite. The "Type B" of the Cambridge Instrument Co. would probably be very suitable, but the instrument actually used was one employing a four-electrode valve, which has been described elsewhere.* The difficulty encountered, owing to low insulation resistance of the grid condenser, and the means of overcoming it, are described in a later section of this article.

A simplified diagram of connections of the test is shown in Fig. 2. *L* is the choke under test, *R* the non-inductive rheostat. D.C. is

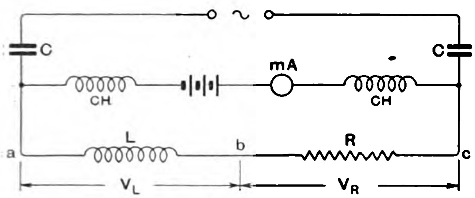

Fig. 2.

supplied by the battery shown, through the moving-coil milliammeter *mA*, and the small chokes *CH*. The latter are to prevent the A.C. supply from sending a heavy current through the battery and milliammeter and damaging them, or affecting the reading. The battery is provided with tappings, and an adjustable resistance arranged as a potentiometer so as to be able to regulate the D.C. current; these are omitted from the diagram to simplify it.

A.C. is supplied to *L* and *R* from a small transformer (not shown in figure), with a potentiometer adjustment to the primary for regulating purposes; the A.C. supply passes through the condensers *C* (2μF paper condensers). This prevents the D.C. supply being short-circuited through the secondary of the transformer, and ensures that all the D.C. passing through the milliammeter *mA* passes through the choke under test.

(It may be suggested that if a transformer is being tested, it is unnecessary to make these elaborate arrangements to separate the D.C. and A.C. supplies, for the D.C. can be passed through the secondary while the slope-inductance of the primary is being tested with A.C., and *vice versa.*)

The points marked *a*, *b*, and *c* in Fig. 2 are connected to a change-over switch, so that the Moullin voltmeter can be connected either across *ab* or across *bc*, so as to measure the alternating potentials V_L and V_R across *L* and *R* respectively.

Method of taking a Reading.

The D.C. supply being adjusted to give approximately the number of D.C. milliamps required, the A.C. supply is switched off and the Moullin voltmeter switch tried in both positions. There will be a large kick on closing the switch, but the reading should then return to zero. Probably it will not quite do this, for unless the insulation resistance of the grid condenser is sensibly infinite compared to the grid-leak resistance, the combination forms a potential divider and applies a D.C. voltage to the grid. Thus, supposing we have 100 volts D.C. across the voltmeter, if the insulation resistance of the condenser is 200 megohms, and the grid-leak 2 megohms, we shall have 1 volt D.C. applied to the grid. In the case of a temporary arrangement rigged up for the purpose, a good mica condenser should be used, or, preferably, several in series (the value is unimportant, as it will merely affect the calibration, but the larger the capacity the better). If the instrument is contained in a box, and it is inconvenient to change the grid condenser, a good well-insulated condenser, of as large a capacity as possible, should be connected in series with the grid terminal of the voltmeter, or, if necessary, several in series may be used. It will then be necessary to recalibrate the voltmeter, but as only one point on the scale (that corresponding to 3 volts) is required, this is not a serious inconvenience.

The A.C. supply is now switched on, and by adjustment of the rheostat *R* and the supply to the primary of the transformer, the Moullin voltmeter is made to read the

* See "A Valve Voltmeter with Self-contained Batteries."—*Journal of Scientific Instruments*, March, 1926, p. 181.

same value, namely 3 volts, for either position of the switch. The D.C. may then need a final readjustment, but the process does not take as long as it sounds, for the exact value of the D.C. is not important as long as it is read accurately on the milliammeter *mA*. Having noted the reading R' of the rheostat R, we have the impedance (say Z') of L numerically equal to R', for choke and rheostat carry the same current, and have the same 3 volts P.D. across them.

We may again neglect the effective resistance r' of the choke as small compared with the reactance X', and write

$$X' = Z' \text{ (nearly)} \quad .. \quad (3)$$

and we have the slope-inductance

$$L' = X'/2\pi f \quad .. \quad .. \quad (4)$$

Errors from Leaks.

Trouble is often caused through the presence of stray earths, to which the grid-rectifying type of Moullin voltmeter is peculiarly sensitive. If the conditions of supply allow, this source of trouble can be avoided by arranging that the filament of the Moullin voltmeter valve is always connected to earth. In this case it is convenient to arrange the change-over switch so that this terminal of the voltmeter is always joined to the point b in Fig. 2.

Results of Test.

The results of this test for the same commercial choke as Fig. 1 are plotted in Fig. 3, the slope-inductance for a 3-volt 90-cycle signal as ordinates, the D.C. current through the choke as abscissæ. Note the steady fall of inductance from about 60 henries with no D.C. to about 14 henries with 14 milliamps D.C.

With the anode currents usual in an amplifier, it will be seen that the effective inductance is of the order of 30 to 40 henries.

Tests at one or two points, for low D.C. currents, were made on other chokes and transformers that happened to be available, but if large D.C. currents flow, the test is rather a strenuous one, and may cause damage. It was found that transformers gave very similar results to chokes, and that the higher values were not given by the best transformers in every case! The effects of self-capacity have, of course, a large influence, and this test is designed to eliminate them.

For comparison purposes, a similar test was made on an ex-Government choke, a Post Office "1,000 ohms telephone switchboard indicator" such as were obtainable a year or so ago at 6d. or 1s.

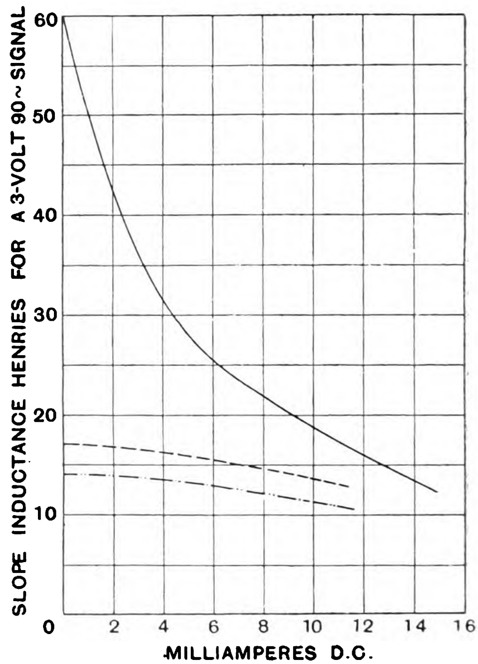

Fig. 3.

Two tests were made, one with the adjustable lid removed, so as to leave a large air-gap, and one with the lid closed as tightly as possible. The results are plotted on Fig. 3 in dotted lines.

Owing to the air-gap, the drop in inductance is much less than in the case of a choke having a closed iron core, and at about 10 milliamps D.C. the inductances of the two are very similar, and one might suppose that they would be equally suitable for use in an amplifier. The two chokes were therefore tried in the anode circuit of the last valve (a D.E.5), the loud-speaker being connected across them through a condenser. The reproduction with the closed-core choke was as good as with the loud-speaker connected in the anode circuit of the last valve, and no decrease of volume was noticeable,

but with the small "indicator" choke the volume was much reduced, and quality bad, probably due to large self-capacity.

APPENDIX I.

Discussion of Error made in neglecting Effective Coil Resistance.

Let the true reactance of the choke be X, where :

$$X^2 = Z^2 - (R + r)^2 \quad \ldots \quad \ldots \quad (5)$$

Let the calculated reactance, neglecting the resistance r be Y

where $$Y^2 = Z^2 - R^2 \quad \ldots \quad \ldots \quad \ldots \quad (5\text{A})$$

Then $$X^2 = Y^2 - (2rR + r^2)$$

or $$X = [Y - (2rR - r^2)]^{\frac{1}{2}} \quad \ldots \quad (5\text{B})$$

Expanding the square bracket by binomial as far as the second term,

$$X = Y - \frac{1}{2Y}(2Rr + r^2)$$

$$= Y - \frac{r}{Y}(R + \tfrac{1}{2}r) \quad \ldots \quad \ldots \quad (5\text{C})$$

and the error e is then :—

$$e = (Y - X) = \frac{r}{Y}(R + \tfrac{1}{2}r)$$

or $$e/Y = \frac{r}{Y^2}(R + \tfrac{1}{2}r) \quad \ldots \quad \ldots \quad (5\text{D})$$

Now, if the iron and copper losses are about equal, the effective A.C. resistance will be about twice the D.C. resistance, which is about 1,965 ohms ; say $r = 4{,}000$.

e/Y will clearly be greatest when Y is smallest, and for given Y will be greatest when R is a maximum.

The value of R must then be kept as small as possible without obtaining too small a P.D. across it to be read on the voltmeter.

The worst case actually occurring was $Y = 40{,}000$, $R = 1{,}000$, for which

$$e/Y = \frac{4{,}000}{(40{,}000)^2}\left(10{,}000 + \frac{4{,}000}{2}\right) = \frac{1{,}200}{40{,}000}$$

or 3 per cent.

This is less than the probable error of the readings, which may amount to 5 per cent., and we may therefore say that our results for A.C. inductance are too large by an amount which may be about 5 per cent. at most (the error from neglecting r for greater values of Y is of course much less).

In the test of effective or slope-inductance, the error is different, but the process of obtaining it is similar.

Let X be the true reactance of the choke, and Y the calculated reactance, neglecting the effective resistance r of the choke. Y is then really the impedance of the choke, and—

$$Y^2 = X^2 + r^2 \quad \ldots \quad \ldots \quad (6)$$

We adjusted the resistance R of the rheostat so that $$R = Y \quad \ldots \quad \ldots \quad (6\text{A})$$

whence $$X^2 = Y^2 - r^2 = R^2 - r^2 \quad \ldots \quad (6\text{B})$$

or $$X = (R^2 - r^2)^{\frac{1}{2}} \quad \ldots \quad \ldots \quad (6\text{C})$$

Expanding the bracket by binomial, as before, as far as the second term :—

$$X = R - \frac{r^2}{2R} = Y - \frac{r^2}{2R}$$

and the error $e = Y - X = r^2/2R$

or $$e/Y = \tfrac{1}{2}(r/R)^2 \quad \ldots \quad \ldots \quad (6\text{D})$$

In the worst case here, we have, assuming $r = 4{,}000$ as before, $R = 16{,}000$,

whence $e/Y = \frac{1}{2}(4{,}000/16{,}000)^2 = \frac{1}{2}(\frac{1}{4})^2 = \frac{1}{32}$

or 3 per cent.

The error is then about the same as before.

APPENDIX II.

Proof that the curve of Fig. 1 is, to suitable scales, the μH curve of the iron (plotted on log. paper).

Let L = A.C. inductance.

l and a = length and cross-section of the iron flux-path.

T = number of turns.

I = maximum current.

B = maximum induction.

H = maximum magnetising force.

ϕ = maximum flux.

$$4\pi IT/10 = Hl \quad \ldots \quad \ldots \quad (7)$$

whence $$H = \{4\pi T/10l\}I \quad \ldots \quad \ldots \quad (8)$$

so that H is proportional to $\mathfrak{I}$.

Further $$L = \frac{\phi T}{I} = \frac{BaT}{I} = \mu \cdot \frac{H}{I} \cdot aT$$

or $$\mu = L \times \frac{1}{aT} \times \frac{I}{H} = L \times \frac{1}{aT} \times \frac{10l}{4\pi T}$$

$$\mu = \{10l/4\pi aT^2\}L \quad \ldots \quad \ldots \quad (9)$$

so that μ is proportional to L.

Now if we assume a sinusoidal current, $\mathfrak{I} = \sqrt{2}I$, where $\mathfrak{I}$ is the R.M.S. current,

thence $$H = \frac{4\pi}{10\sqrt{2}} \frac{T}{l} \cdot \mathfrak{I}.$$

L.T. & H.T. Supply from D.C. Main.

THE accompanying diagram, Fig. 1, shows a three-valve receiver connected to an arrangement for obtaining H.T. and grid bias from a D.C. 250-volt town main supply, where the + side of the system is earthed.

The arrangement is similar to that described in my article on "L.T. and H.T. from a 250-volt D.C. Supply" in the February number of *E.W. & W.E.* A 60-ohm resistance provided with tappings connected to wander plug sockets supplies a range of grid bias voltage. This resistance consists of several 12-ohm M.F. lamps in series and is connected in circuit between the choke coil and negative battery terminal. It gives every satisfaction with entire absence of hum.

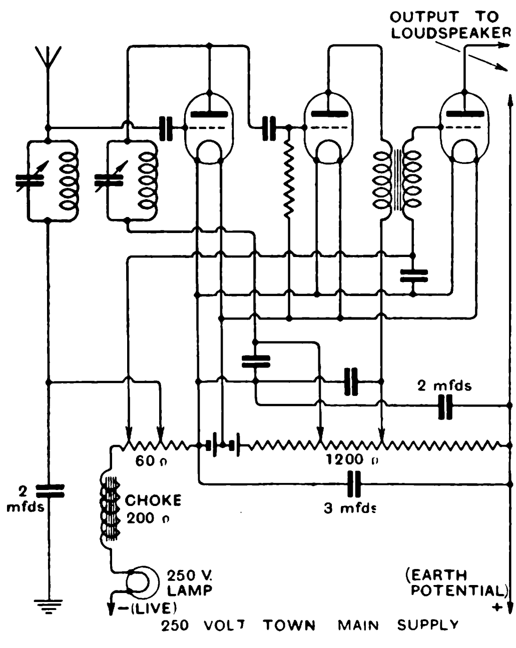

Fig. 1.

If grid bias is desired for only the last valve, this resistance may take the form of a rheostat.

Care must be taken that the reservoir condensers are connected directly to the L.T. busbars. A slight modification in this circuit may cause these condensers to bring in a considerable hum from town main supply, when, with direct connections, they should slightly contribute towards smoothing of ripple.

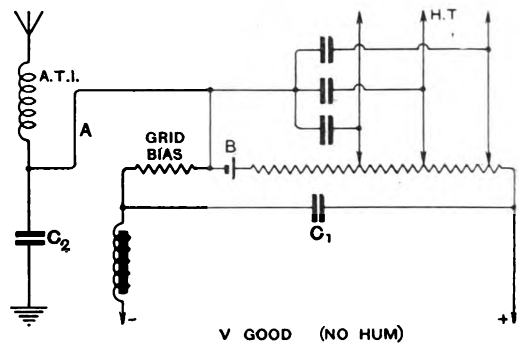

Fig. 2. *Arrangement for obtaining H.T. and grid bias from 250 volt D.C. town main supply.*

Figs. 2 to 6 show several possible arrangements together with a brief account of their behaviour in actual use.

The following explanation for presence of hum in circuits shown in Figs. 4 and 6 is deduced from the experimental results obtained. The ripple passing through the choke coil thereafter splits up into two main

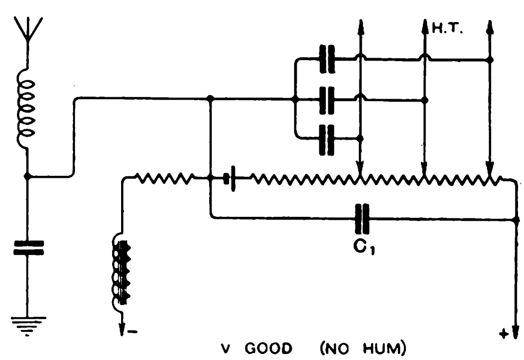

Fig. 3. *Another arrangement also giving excellent results.*

portions, one of which is by-passed, through condenser C_1, to the positive supply terminal; the other portion travels via leads *B* and *A* (Fig. 2) to earth via condenser C_2. There are also two other very small components,

one of which travels through the 1,200-ohm resistance to the positive supply terminal. The other goes up through the anode

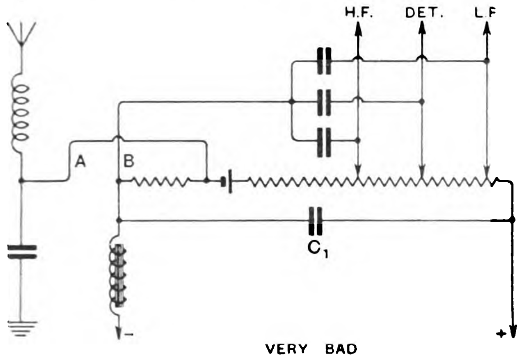

Fig. 4. *Showing an arrangement with which the hum is very bad indeed. This arrangement is similar to that in Fig. 5, but the reservoir condensers are connected up. In this case the reservoir condensers cause considerable hum, owing to position of connection B in circuit.*

reservoir condensers and back through a portion of the 1,200-ohm resistance to the positive supply terminal. Both these components are harmless and only the component which takes the path through condenser C_2 will at present be discussed.

In Fig. 4 the ripple passing through the choke coil would, if there were no resistance in circuit, travel direct to earth through condenser C_2. The presence of the grid bias resistance causes a small portion to be

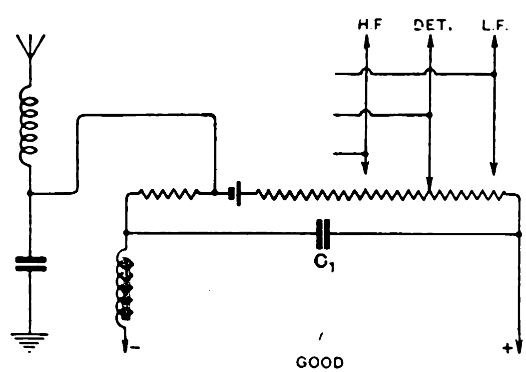

Fig. 5. *Showing same arrangement as Fig. 2, but reservoir condensers are disconnected. This arrangement gives quite good results but there is a slight trace of hum which indicates that the reservoir condensers slightly assist smoothing.*

diverted through lead B to the anode condensers returning through the valve to the battery and to earth through condenser C_2.

This theory is supported by the fact that the hum ceases when the circuit is broken at either A or B and also when the 60-ohm resistance is shorted.

The conditions in circuit shown in Fig. 6 are somewhat more complicated.

This circuit is similar to that shown in Fig. 5, but in this case the L.F. anode reservoir condenser is connected up and the L.F. wander plug is inserted in an anode supply socket. The anode circuit is, however, broken at the L.F. valve holder, and the L.F. valve filament unlighted. The reservoir condenser, on detector anode supply, is disconnected.

It will be gathered from the data obtained

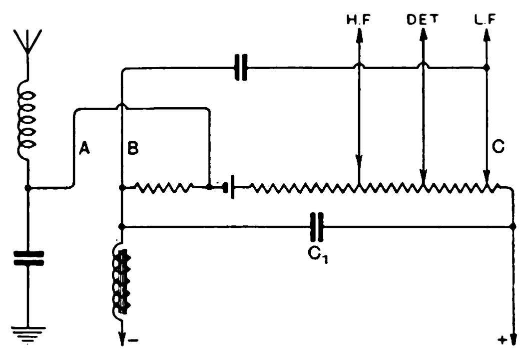

Fig. 6. *An arrangement in which there is no hum when L.F. valve wander plug is at the extreme positive end of resistance. The hum becomes evident as the plug approaches the detector wander plug. Hum is very bad when L.F. wander plug lies between detector and battery but it disappears when L.F. plug is directly connected to the battery.*

(see note below Fig. 6) that the ripple, diverted by means of the 60-ohm resistance, passes up through the L.F. anode reservoir condenser, down the L.F. wander plug, thence along a portion of the 1,200-ohm resistance to the detector wander plug to the detector valve and back via battery and thereafter to earth through lead A and condenser C_2

In support of this theory the hum ceases when circuit is broken at A, B or C. It also ceases when the L.F. wander plug is inserted at the extreme positive end of the 1,200-ohm

resistance (owing to ripple having a direct return path through the positive supply terminal).

It also ceases when the L.F. wander plug is directly connected to the battery terminal as the circuit then becomes shorted to earth via lead *A* and condenser C_2.

The operation of the circuit, shown in Fig. 6, has been dealt with in some detail as it serves to demonstrate the important part an apparently trivial detail may play in the working of a piece of apparatus. It was on such a circuit that the writer made his preliminary experiments, although it was ultimately intended to adopt that shown in Fig. 3. It so happened that the arrangement as shown in Fig. 6 could be experimented with without interfering with the wiring inside panel. The tests were carried out, in the first instance, with the detector valve only and the L.F. wander plug was simply pushed into a vacant socket to be out of the way. Tests were made with various types of resistance such as filament rheostat, wire wound resistance, non-inductive resistances and lamp resistances. A hum was experienced in the first three cases and no hum in the last test. An inductive resistance would, of course, accentuate the hum, but in this instance the improvement noted was not due to any difference in the characteristics of the different resistances but to a change in the position of the L.F. wander plug. This happened to be moved down one socket at the same time as the change was made from wire resistances to lamp resistances. This change, it afterwards transpired, altered the position from that of maximum hum to that of minimum hum. The arrangement shown in Fig. 3 is that adopted by the writer and it gives every satisfaction with all three valves in operation.

A. ROBERTSON.

Design and Construction of a Superheterodyne Receiver.

By P. K. Turner, A.M.I.E.E.

(*Continued from page 292 of May issue.*)

A SIMPLE modification of the circuits of Figs. 8 and 9 (p. 292 May issue) makes negligible the objections to these circuits there referred to. This modification, as shown in Fig. 10, is based on substituting a double condenser, C_2C_3, for C_2, and connecting the centre point to the valve filament. In this way our bridge is completed by two condenser arms, of low impedance compared to the previous ones. C_2, of course, is shunted by the valve impedance, but as this is considerably higher than the reactance of C_3 it exercises only a small effect on the total impedance of the C_3 arm, and this effect can be largely balanced out by putting a corresponding load across

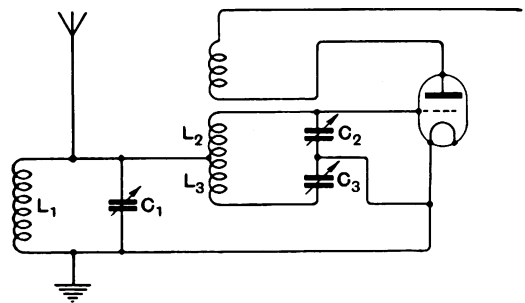

Fig. 10. *The split condenser* C_2C_3, *shown here, is the real solution of the difficulties met with in the previous three circuits.*

C_3. For those who are not accustomed to think in impedances, perhaps the analogous case in Figs. 11 and 12 will be clearer.

In Fig. 11 the upper resistance is variable, and it is obvious that at either extreme of its variation there is a 1 : 2 or 2 : 1 ratio between the two resistances. Now suppose that we have, as in Fig. 14, arms of low resistance (100 ohms), with the high resistance arms across them. Working by the well-known formulæ for parallel resistances, we find 99 ohms for the net resistance of the fixed arm, while the upper one varies from 98 to 99.5 ohms, or a change of only 1½ per cent. in the balance, instead of a change of 4 : 1 in Fig. 13.

This type of circuit was eventually adopted, as shown in Fig. 13. It was desired to be able to use a frame or an open aerial, but the arrangements for this, as well

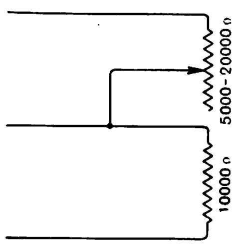

Fig. 11.

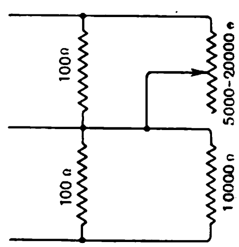

Fig. 12.

Figs. 11 and 12. *The article shows how these resistance circuits are analogies of Figs. 9 and 10.*

as the values of the various components, will be dealt with later, after the theoretical diagram has been completed. It will be noted that a grid-leak and condenser have been included. At the time, I was still not sure whether it would pay to sacrifice the increased efficiency of the grid current detector for the lessened harmonics of the anode current type; it was obviously simpler to include the condenser, and short it afterwards if necessary.

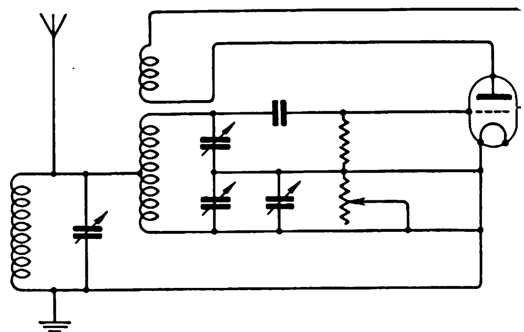

Fig. 13. *The final circuit arrangement, in which errors of balance are negligible.*

The rest of the set, as regards preliminary design, is simple enough, and is shown in Fig. 14—it may be said that the filling-in

of the details is not so simple. There is a choice of two alternatives at the point *A*, where the rectified output from the second detector is thrown back to an earlier valve. These are shown in Fig. 15(a) and 15(b). There are two points that might influence one's choice; the effect of the necessary by-pass condenser on the audio-frequency tone, and the possibility of getting the I.F. component (b) needs an extra component (the choke). However, it was eventually decided to include the choke and use (b).

We thus have the first theoretical diagram—except for the filament circuit—as shown in Fig. 14.* Before we begin to consider the detail of this, one important question must be settled: What is to be the intermediate frequency?

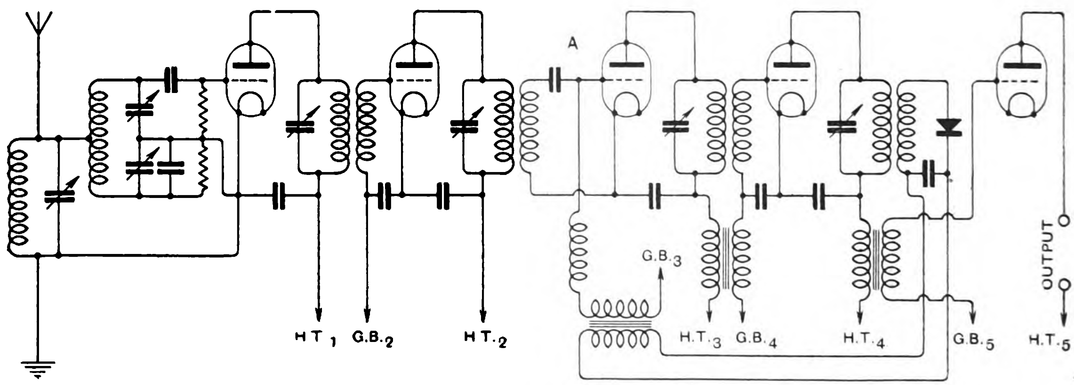

Fig. 14. *Here we have a preliminary sketch of the complete circuit of the set, with non-essentials and details omitted for simplicity.*

in the second detector output thrown back with the audio, which would lead to instability. As regards the first point, there is no choice; but as regards the second point (b) is the better, for the I.F. choke *Ch.* not only stops the normal I.F. from leaking down to the L.F. transformer, but also stops the reverse action. On the other hand, the effect is not usually an important one, and

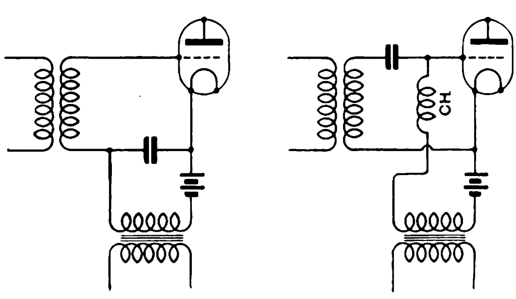

Fig. 15. *Two alternative arrangements for the throw-back transformer;* (a) *is the most economical,* (b) *probably the better.*

If there were no question of Daventry and similar stations, it would be easy. Our preliminary consideration of the question has shown that there is a wide latitude. But if we want to receive up to, say, 2,600 metres (Paris) the intermediate wavelength must be not less than, say, 6,000 metres, or 50kC. Now, in many cases it would make little difference whether we used 6,000 or 10,000 metres. But in this set it is proposed to use two of the valves for both I.F. and L.F., and this makes things just a bit more difficult. For, in this case, both the primaries and secondaries of the L.F. transformers need by-pass condensers These should be large enough not to offer too much reactance at the intermediate frequency; at the same time, if they are large, they will upset the performance of the L.F. transformers at the higher end of the audio-range.

Now, the lower the intermediate frequency the larger these condensers must be; so we desire to keep the I.F. high. Further, there is a great advantage in having a choice of I.F.s available. Any one station, as we

all know, can be recevied at two settings of the oscillator. By the same token, any one setting will beat with two stations, and if (like the writer) one happens to live only two miles from a station, one is likely to find that it interferes on the second setting.

For example, with an I.F. of about 3,000 metres London and Birmingham will very likely clash,* and it may be a great convenience to be able to change the I.F., when they are separated at once.

These two points decided me to try something that I believe to be new. I decided to use an I.F. of about 3,000 metres, or 100kC, and to put *variable* condensers on all the I.F. transformers, the condensers being all operated from one knob. Then for the long wave stations the first valve is stopped from oscillating, and the I.F. amplifier used direct and tuned to the signal. I may as well confess here and now that this device, in spite of its obvious advantages, is by no means free from "crabs." It is expensive and needs a lot of room, and it is not so easy to get stability *and* efficiency at various settings of the I.F. tuning condensers.

At first I designed some rather intriguing switch-circuits to put the incoming signal through to the second valve and simultaneously cut off the filament voltage of the first. It was not till the set had been actually built and tried out that I suddenly perceived the error of my ways. Of course, it was only necessary to stop the first valve from oscillating and tune the aerial circuit to the long wave to be all in order. True, the first valve probably works rather inefficiently, but every little helps.

The next question was as to valves, because this affected the filament circuit. I wanted freedom to use different valves, but obviously all the I.F. valves had to be alike, if the I.F. circuits were all to be tuned together. I therefore designed the circuit for 6 volts, but provided rheostats. As, however, the set would not always be handled by myself, I decided to provide safeguards against excessive filament heat, so that the circuits contain provision for screw-in fixed resistors as well as the rheostats.

By changing these, it is always possible to ensure that, even with the rheostats cut right out, no valve can be heavily overloaded, while there is still the ability to control the filaments, if it is really necessary. For example, the first valve is separately controlled. If one wishes to use a 306 valve, a 45-ohm fixed resistor is used, which puts a limit of about 3.2 volts on the filament even with the rheostat cut right out. The rheostat is a 30-ohm, and can be used to control the valve when needed.

In view of the fact that the three I.F. valves should always be of the same type, they are all controlled from one rheostat, a third control being fitted for the final power valve.

Since I expected to use different valves from time to time, I desired to have a filament voltmeter always available—for it is pretty useless to try to judge the voltage on dull emitters by their appearance. I was also quite determined to have a milliammeter in circuit, as it is such a useful guide to adjustment and also for fault-finding, apart from its being a sure indicator of distortion due to the valves. As will be shown later, I was able to use the same meter for both purposes.

It was at this stage that I began to consider what tappings I should need on the grid and anode batteries. Again, in view of the fact that I wished to experiment with various valves, I decided to run one anode tap for the "detoss," one for the three I.F.s, and one for the power valve. The same was done for the grid battery. Since this was to be inside the set, it would obviously be just as easy to connect the earth point of the "detoss" grid circuit to a flexible tap as to make a permanent connection to either side of the filament, and I decided on this.

At last, then, I was ready to design out the final theoretical diagram, and, as usual, I started with the filament circuit. I always find it best to neglect this in preliminary work, to begin with it in the final schematic diagram, but to leave it to last again in the layout.

It was decided at once that all the rheostats must go on the positive side of the filaments. It is one of the advantages of fixed resistors that they may be inserted in the negative leg, and thus in many cases enough grid bias may be got, without a special battery, for all except the last valve.

* At the time of writing, Birmingham was on its old wave of 480 metres or thereabouts.

But this is quite unjustifiable with variable filament rheostats, since every adjustment of the resistance alters the grid bias. It was further decided that L.T.— should be the "bus-bar," to which should be connected all by-pass condensers, earth (when used), screens, etc., and also H.T. — and G.B.+.

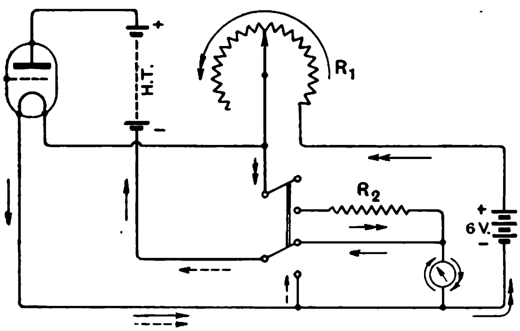

Fig. 16. *In order to show anode mA or filament volts on the same meter, a switch is arranged (as shown).*

A little thought had to be expended on the arrangement for switching the meter to register either filament volts or H.T. milliamps. One or two arrangements which worked admirably for one valve had the disadvantage that when extended to deal with several the slightest error in operating the switches led to a short. That finally adopted is shown in its simplest form in Fig. 16. Here R_1 is the filament rheostat and R_2 a suitable high resistance to make the milliammeter work as a voltmeter. It is clear from the diagram that with the switch in its present position the return current from filament to — of the H.T. battery follows the line of the plain arrows through the meter. On switching over, this H.T. current flows according to the dotted arrows and does not affect the meter, while the latter, with R_2 in series, is placed across the filament and thus indicates filament volts as shown by the double-headed arrows. Since the two currents flow in opposite directions, a central zero instrument must be used.

The resistance R_2 may be found as follows: Suppose the full deflection of the meter is 10mA, and we want this to mean 6 volts, Ohm's Law ($R=E/C$) tells us that the resistance of R_2 and the meter together must be $6/.01=600$ ohms. The makers will always state what is the resistance of the meter, and R_2 can be found approximately from any wire tables, and checked and adjusted by comparing the milliammeter and R_2 against a voltmeter—or the calibration department of *E.W. & W.E.* would undertake the work.

For use with several valves, one slight modification must be made: "R_2" must go to the arm of the switch and "Fil.+" to the contact: the reason for this will be appreciated on studying Fig. 17, which shows the full filament circuit for the set. The switches are, of course, Dewar keys, which are most effective and convenient for such work.

It will be seen that four such keys are included in Fig. 17, of which one is simply a switch for the H.T. and L.T. — leads, thus forming the main on-off switch for the set. The other three are connected as in Fig. 17, the left-hand contacts of each key being for filament voltage and the right-hand ones for the H.T. current circuit. In the position shown, the main switch is off. On pressing the key, the centre contacts rise into contact with the top bars. There is then a complete circuit from the right-hand contacts of this switch *via* the middle and bottom right contacts of all the keys, and the meter, thus connecting H.T. — to Fil.—. On pressing

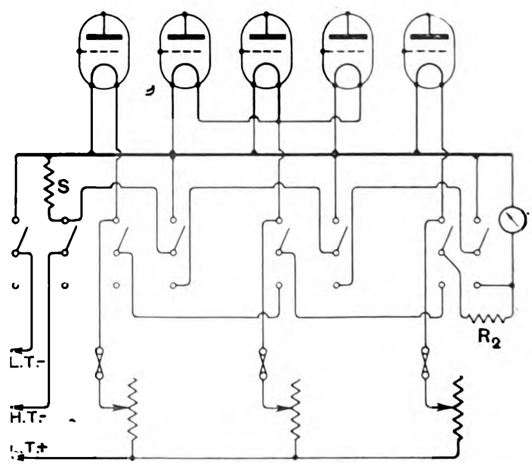

Fig. 17. *This is the circuit of Fig. 16, elaborated to show (1) the total anode current; (2) the filament volts of all valves one at a time.*

any key, the right centre contact rises and makes contact with the upper bar, thus disconnecting H.T.— from the meter and putting it straight to the Fil.—. At the

same time, the left centre contact of the key pressed rises and connects the meter through R_2 to the corresponding Fil. +. If by accident two keys are pressed at once, nothing happens except that the meter reads the voltage of the nearest filament.

In the actual set, S had to be included. This is a shunt which comes across the meter whenever it is being used as a milliammeter, and was put in because the only available instrument was a 10mA meter, and it was desired to read up to 20mA.

When this part of the circuit had been wired up, the glass of the meter was removed, and the existing scale covered by a paper one, of which one side was marked in black to read 20mA, and the other in red to read volts: the graduation was done against outside meters known to be fairly accurate.

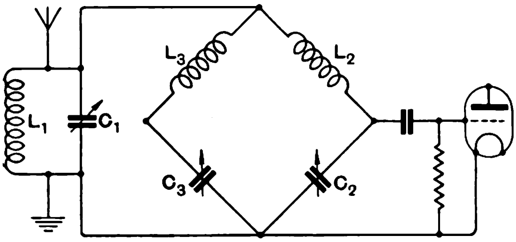

Fig. 18. *In the detailed design of the input circuit, it must not be forgotten that the oscillator coils and condensers come across the aerial circuit and affect its tuning.*

To avoid confusion, this filament circuit will not be shown in later diagrams, it being understood that the grid and anode circuits are connected (for H.F. and audio currents) to the Filament negative busbar shown as a heavy line in Fig. 17.

The next task was to think out in detail the arrangements for the grid and anode circuits. It had already been decided that the I.F. should be 100kC (3,000 metres) or thereabouts; and it was desired to have the transformers of a plug-in type, with a view to test and experiment. It was decided to install McMichael air-cores as a commencement, as they were compact, and also lent themselves conveniently to the use of reaction if desired. This led naturally to the McMichael "Autodyne Unit" for the twin coils of the oscillator. As it was desired to get a fairly wide wave-length range, it was decided to use a twin .0005 condenser across these coils.

It was realised that the presence of these coils and condensers would have a distinct effect on the aerial tuning, for, as will be seen from Fig. 18 (which is Fig. 13 drawn differently) they come across the frame or A.T.I. whichever is used. It must be remembered that $L_2L_3C_2C_3$ control the *oscillator* frequency and are therefore out of tune with the aerial to the amount of 100kC (the intermediate frequency). If they are tuned to a longer wave than the aerial the condensers will be too large to tune with the aerial, they will offer too little reactance, and the whole of $L_2L_3C_2C_3$ will act as an inductance in parallel with L_1. If, on the contrary, $L_2L_3C_2C_3$ is tuned to the shorter wave than the aerial, they will act as a capacity across C_1. The matter is further complicated by any mutual inductance between L_2 and L_3, and the precise calculation of the effects is quite tricky. It leads to the important feature that if connected up as shown, and arranged so that L_2 and L_3 form one coil in Fig. 13, signals will be stronger when the oscillator is tuned to a shorter wave than the signal. This is a valuable feature in diminishing interference. If it is desired to work permanently on the other "channel," with the oscillator set to a longer wave than the signal, the following changes should be made: (1) L_2 and L_3 should have more turns—probably about twice as many; (2) they should be wound in opposition, *i.e.*, *one* of them should be reversed; (3) probably several turns will have to be taken off the frame.

Connected as shown, the McMichael unit, nominally 300-600 metres, gave a range of 200-700 with the two .0005 condensers across it. The smaller unit, nominally 150-300, gave about 120-350 metres.

In order to cope with a wide range of experimental conditions the aerial condenser C_1 was made large (0.001) and a special arrangement of plugs was used for connecting up the frame. This is shown in Fig. 19. Sockets are provided for an outside aerial and earth when desired. To use the frame, F is plugged in. To use a tuning coil, C is plugged in. For short waves on the frame both plugs are inserted, putting the coil socket in parallel with the frame, when a short wave coil may be inserted to cut down the wave length. If one wants a long wave, beyond the range of the frame, the two

plugs (which are Clix) are connected together, which puts coil and frame in series.

Between this arrangement and L_2L_3, however, there is another device : the long wave switch. The connections of this are shown in Fig. 20. All it does is to cut a long-wave coil clear out of circuit or bring it in ; it also shorts the oscillator reaction coil on long waves.

Everything has now been decided up to the first grid except the grid and balancing condensers and leaks. It was decided to make the leaks variable, and as we had previously had good results with the Bretwood, we used these. The grid condenser was made 0.0001. Probably an even smaller value would have been an improvement. From the point of view of detection, this condenser should be large enough to offer

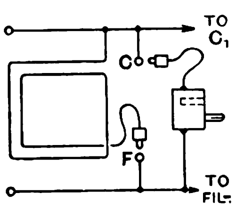

Fig. 19.

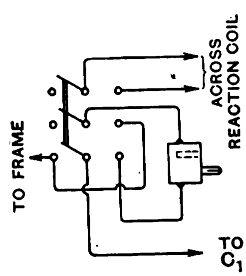

Fig. 20.

Fig. 19. *Two plugs and sockets enable us to use frame and loading coil either alone, in series, or in parallel.*

Fig. 20. *This 3-way switch, thrown to the left, puts aerial to set. On the right, it throws in a series coil for long waves, and at the same time shorts out the oscillator reaction.*

not too great a reactance to the radio frequency input, but at the same time small enough to offer a high reactance to the rectified output. Since in this case the output is at 100,000 cycles as compared with audio frequency for an ordinary detector, the condenser should be kept smaller than usual, provided this does not interfere with the valve's performance as an oscillator. Since only low-power oscillations are needed, this latter point is not of great importance.

Lastly, as to the balancing condenser. This has to balance out the apparent working capacity of the valve, and should be made variable, with a maximum capacity of 50-100$\mu\mu$F. One of the single-plate neutrodyne or "vernier" condensers on the market will be suitable.

As already explained, it is simplest to leave the filament connection variable, so that the grid battery can be used to give a volt or so + or — potential. The reason is that this valve has, firstly, to oscillate with as few harmonics as possible, and secondly, to rectify with as few harmonics *of the rectified frequency* as possible ; and to meet all these requirements it is best to have a free hand with both grid and anode voltages. Do not imagine that the adjustment is difficult ; the set will work, and work well, with any reasonable voltages ; but if it is to be used within a mile or so of a 3kW station, that station may tune in in more than two places on the scale if these harmonics are not kept down. In actual practice, I have found that, for M-O D.E.3B, Mullard H.F. 06, and Burndept H. 310, about 90 volts on anode, and grid circuit straight to filament negative, gave the best results, while with Burndept H.L. 512, one cell negative grid bias was an improvement. Unfortunately, one cannot very easily forecast the requirements in advance, for it is very difficult to calculate what will be the mean grid potential of a valve with condenser and leak when that valve is oscillating. Finally, therefore, we have Fig. 21 as the circuit as far as the output of the first valve. As regards the values of components not already decided, we have found that a small frame about 2 ft. × 1 ft. needed 8 turns, and a large one, 3ft.×3ft.,needed 5 turns. These were tapped once (the 8-turn at 5 and the 5-turn at 3), and in this way each would tune from 200 to 600 metres without troubling to use a plug-in coil. The long-wave coil will probably need to be 150 or 200 turns. For the 300-600 twin coil a reactor marked "30" proved the best, and for the 150-300 a "20," or better still, a "20" rewound with only three-quarters of its original turns. The condenser C_4 is simply to by-pass the grid battery and if the flexible plug lead (as in our case) is only a few inches long, it can be safely omitted. If included, it may be anything from .001 to .005.

It may quite possibly be desirable to modify the arrangement of the anode circuit. There are two obvious possibilities, and the choice will depend on whether it is desired to tune the primaries or secondaries of the I.F. transformers. For equal "goodness" of design, it will probably be most

efficient to tune the secondaries, but it is often more convenient (and gives a longer range of wave-lengths, if desired) to tune the primaries. If the latter is done—and as will be seen later, it is especially convenient with a crystal detector—then Fig. 21 gives the correct wiring, the tuning condenser across the primary also acting as a of the I.F. stages. A point which needs consideration straight away is that of reaction, or on the contrary, stabilising. If transformers of fairly high step-up are used, it is quite likely that stabilisation will be called for, especially if the tuning condensers are small—these are both points making for high amplification per stage, and compara-

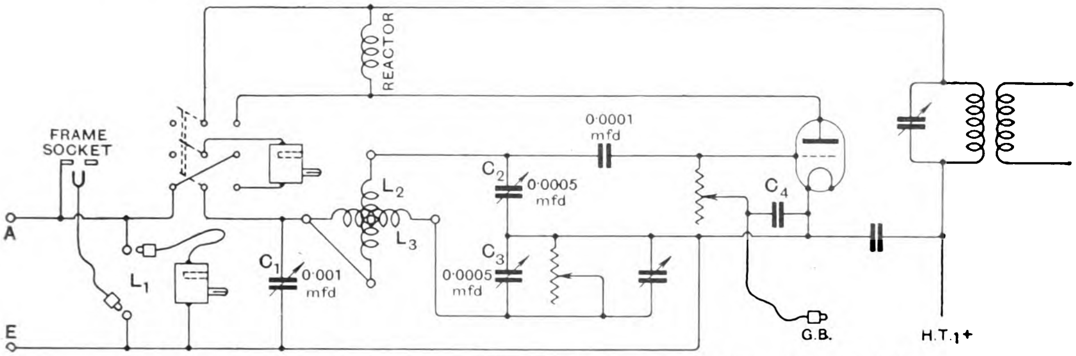

Fig. 21. *Here we have, with all frills, the complete circuit from aerial as far as the output of the first valve.*

by-pass for the H.F. components in the detector output. If, on the other hand, the secondary is to be tuned, and the primary is of low self-capacity, Fig. 22 shows the best method. The primary acts as an H.F. choke, and the .0001 condenser in the lead to the reaction coil, as an I.F. stopper. It may be advisable to reduce the latter to

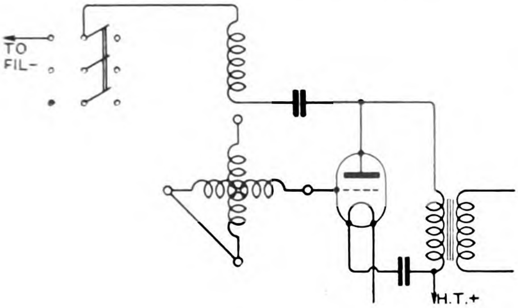

Fig. 22. *If the I.F. transformers have* NOT *got tuning condensers across their primaries, this form of oscillator reaction circuit must be used in place of that in Fig.* 21.

.00005. Also, it will be noted that the long-wave switch connections are changed so as to open-circuit the shunt reaction coil path on long waves.

Now we must begin to consider the design tively low selectivity. On the other hand, if the transformer step-up is kept low—say $1\frac{1}{2}$ to 1—and if the I.F. is such that the transformers tune to it with a fair amount of capacity (these points giving extreme selectivity but lower amplification), then with good design the I.F. amplifier will be so stable as to stand quite a lot of positive reaction.

These two points perhaps need a little further treatment. That of selectivity was treated by the writer in a recent issue of *E.W. & W.E.** This dealt primarily with amplifiers of the tuned anode type; but since a "tuned anode" circuit is essentially a 1 to 1 transformer of zero magnetic leakage, and since the tuning conditions of any tuned transformer may be reduced to those of a 1 to 1 transformer by working on "equivalent capacities," the principles of that article will apply. It was there shown that small windings and large capacities give great selectivity, but a certain reduction in strength. If the condensers are *too* great, one may easily, with several stages, get excessive selectivity and cut down the strength of the side-bands giving the higher notes.

* "Selective Amplifiers," *E.W. & W.E.*, October, 1925, pp. 801 *et seq.*

It will be noted that on p. 805 of the article just referred to, there is given the example of finding the right values of the condenser for "amplifying at 3,000 metres, to give a drop of not more than 20 per cent. in the strength of the side-bands at 5,000 cycles audio-frequency with valves of 30,000 ohms anode impedance." It may perhaps be a matter for surprise that the conditions there specified fit in so aptly with our present requirements. To be perfectly frank, that article was inspired by the actual calculations made for this receiver, the writer finding to his disgust that no one else had written an article from which he could crib the necessary data.

The example shows that a capacity of 0.0002 is called for across the primary of the transformer, which is what we wish to do here. Had it been desired to use transformers of higher step-up, we should use the same capacity across the primary. Strictly, a correction should be made, because the step-up ratio makes the load on the secondary (due to the next valve) more important ; but the correction is not large (see p. 803 of "Selective Amplifiers," *re* the ratio R_a/R_e). If, on the other hand, we had proposed to use step-up transformers of ratio 1 to 4, and tune the secondaries, we should have divided the .0002 already found by the *square* of the ratio (*i.e.* $4^2=16$), thus getting 0.000012 for the best capacity.

As regards the correct ratio of a tuned transformer for the highest amplification, this is a much more complicated matter. The writer has worked out the analysis fairly completely, but the difficulty is that the best ratio depends essentially on the input impedance of the valve which follows the transformer, and this is quite a difficult thing to forecast. Under average conditions, it is probable that the ratios given in the following little table are about correct :—

TABLE II.

Wavelength.	Ratio.
200— 400	1 : 1
400— 800	1 : 1½
800—1,600	1 : 2
1,600—3,200	1 : 3
3,200 upwards	1 : 4

In every case, of course, if the transformers are to be home-built, the inductance of the tuned winding is to be calculated from the maximum tuning capacity as found above and the desired maximum wavelength. In practice, the winding should be made slightly larger than calculated in this way, to allow for the "demagnetising" effect of the other winding. This correction is practically negligible if the secondary is to be tuned ; but if the primary is to be tuned, and there is a fairly high ratio, so that the secondary is large, then it may be found advisable to increase the primary inductance by say 20 per cent. (or the turns by 10 per cent.) above the value calculated as just shown.

In the particular set we are describing, it had been decided to tune the primaries. To allow for any unexpected effects, it was decided to fit condensers of 0.00025μF, and the No. 3 air-core barrel-type transformers of L. McMichael, Ltd., just filled the bill, giving about 3,000 metres with all the capacity across.

This having been settled, it was noted that these transformers are practically 1 to 1 ratio, so it was expected that the amplification would be fair, the selectivity good, and the amplifier pretty stable. So provision was made for reaction. This, as a matter of fact, is exceptionally convenient with these transformers, as they can be fitted with reactors as desired.

In cases where stability is not expected—or where, though expected, it has not been achieved—one must consider whether to use reverse reaction or whether to stabilise by control of grid potential. I must confess to a strong distaste for this latter method. For a commercial act, to be handled by the unskilled, it has many advantages. But for a set for myself, I prefer magnetic reaction, positive or negative, as may be found necessary. It should be emphasised that this is simply a personal preference : I know of various excellent sets which use potentiometer control.

I am surprised that so many builders of supersonics neglect the importance of this control. On many sets the "stabiliser" is an "occasional" control, not intended to be used frequently. But it is extremely useful. It gives a most powerful control of volume for getting very distant stations,

and is also of great assistance in getting increased selectivity when absolutely necessary. Of course, this may cause loss of high notes from excessive selectivity, so it is equally necessary to avoid its use when best possible tone is needed from a station fairly near.

After all this preliminary thought, one can get down to the details of the I.F. circuits. The first stage is partly shown in Fig. 21; but we give it in full in Fig. 23. It is that part to the left of *AB*. The circuit is typical, and needs no explanation except for the by-pass condensers. It is usually considered sufficient to put in a condenser across the battery, and leave it at that. But, as will be seen shortly, we *must* use these condensers in later stages, and it is always sound practice to have a short H.F. path straight to the filament, so they are included in this stage as well. The reason for the difference in their values is the increased impedance of the grid circuit as a whole, which allows a correspondingly high reactance or low capacity for a by-pass. As to values of H.T. and grid bias, they should be arranged for pure amplification: a bias of 1 cell (say 1.5V) is probably sufficient for all these stages, though I prefer myself to put on 3V as a precautionary measure, as some valves start grid current some way below zero volts. With most valves of μ from 10 to 20, such as will probably be used, 100V on the anodes is the sort of voltage called for.

In putting up these suggestions, of course, I have an eye to the requirements of the later I.F. stages, which are doing L.F. work as well. For the first stage, which is pure I.F., one can neglect distortion to some extent, and if desired use less H.T. and bias. But it seems simpler to run all the I.F. valves alike.

The next stage is that included between the dotted lines *AB* and *CD* in Fig. 23. The first part, the anode circuit, is similar to the previous anode circuit except for the omission of the reaction coil. It therefore needs no remark. The second part, however—the grid circuit of the third valve—has some points needing consideration. We have already gone into the reasons which led to the choice of parallel circuits for the I.F. and L.F. currents. We must now choose values for the splitting choke and condenser.

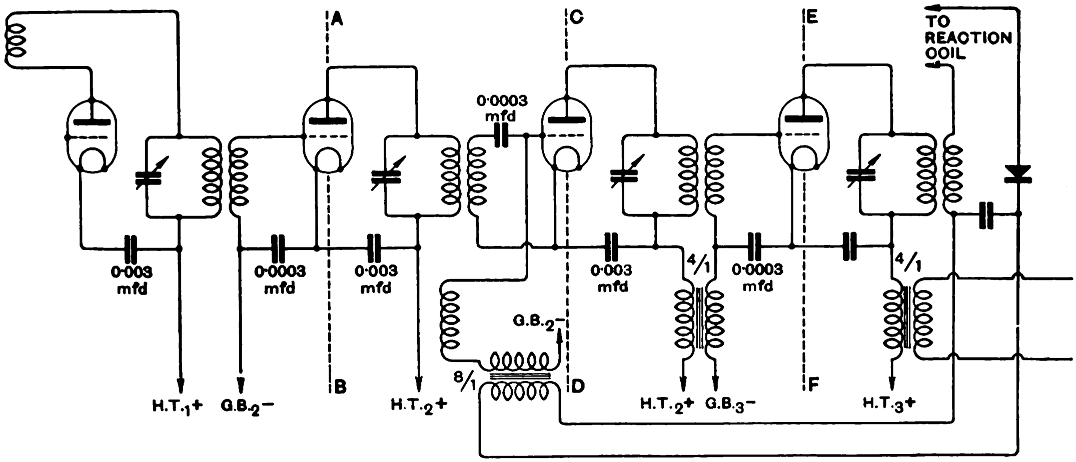

Fig. 23. *Here we have, complete except for battery connections, the circuits of the I.F. amplifier and detector, including the reflexed L.F. circuits.*

The condenser presents the old problem: it must have a low reactance to the I.F. (100kC), but a high reactance to the audio (say 2kC), both "low" and "high" being in comparison with the input impedance of the valve. As will be seen from Fig. 23, we have given this the same value as the grid by-pass condensers in other stages. These are based on the following empirical rule: "To separate audio-frequency from 300 metres, use 0.0001 in grid circuits and

0.001 in anode circuits: if either of the limit frequencies is n times these values, divide the capacity by $\sqrt{n}$." Thus, since your actual limits in this case are 3,000 metres and audio, we have *divided* one frequency by 10, and we therefore *multiply* the 0.0001 by $\sqrt{10}$, getting approximately 0.0003μF.

As another example, take the grid condenser of the first detector. Here the frequencies are (say) 300 metres and 3,000 metres. The latter is 100kC, or say 50 times audio-frequency, so the condenser should be divided by $\sqrt{50}$, or 7, giving 0.000,015. Actually, we used a larger condenser, to help the valve as an oscillator, but on a future occasion, we should try a smaller value.

With regard to the I.F. choke, it is hard to give any definite rule—apparently almost anything will do—provided, of course, it is not *too* small. Ordinary coils of various makes from 400 turns upwards all did fairly well. We finally chose a coil which seemed just a little better than most for this particular purpose, and had the merit of cheapness. It was an Igranic "slab" of 1,800 turns, rated at about 200,000μH, self-capacity about 11$\mu\mu$F. Probably a coil of 2,000 turns of fine wire wound solid in a slot, say $1\frac{1}{2}$ in. bottom diameter, $\frac{1}{8}$ in. wide, and not less than 1 in. deep, would do as well; for in this instance we are not interested in H.F. resistance: low self-capacity is the great factor.

The next stage, between *CD* and *EF*, is again slightly different. Here both the anode and grid circuits are combined L.F. and I.F. The series arrangement was adopted, merely on the ground of saving chokes; for the particular reasons which made the parallel method preferable in the first or "throw-back" stage now no longer apply. There is also a real disadvantage about having several H.F. or I.F. chokes in the same set. Although the I.F. current flowing in such chokes is extremely small if they are efficient, yet it does exist; and their large inductance makes even a small current quite powerful in creating unwanted stray fields. If several are in use, it is quite surprisingly difficult to keep them from picking up from one another, which promptly leads to instability.

The by-pass condensers, transformer, and main tuning condenser are all just as described for previous stages, so that there is really little to say about the I.F. part of this stage: the L.F. part will, of course, be dealt with later.

(*To be continued.*)

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page 285 of May issue.*)

8. The Circular Measure of Angles.

An isosceles triangle is one having two sides equal. It is easy to show from the results of Sect. 5, that the angles opposite these sides will be equal, and therefore that all such triangles with a given angle included between the equal sides will be similar. n such triangles of equal size and with vertical angle $360°/n$ can obviously be combined into a figure such as that shown in Fig. 15. Such a figure is called a regular n-sided polygon.

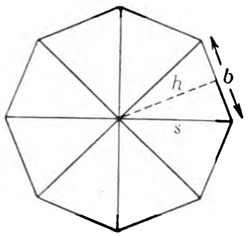

Fig. 15.

(That illustrated is an octagon.) From the preceding discussion of similarity it follows that for any given number of sides n the ratio b/s, and therefore nb/s is constant, *i.e.*, independent of the size of the figure, *i.e.*,

$$nb/s = k_n$$

where k_n depends only on n. Now by sufficiently increasing n the figure can be made to differ by as little as we please from a circle. A circle is in fact the limiting case when n is made infinite, nb then becomes the periphery or circumference of the circle, and s its radius. Thus the ratio

$$circumference/radius = k_\infty$$

is constant for all circles. The constant is the number 6.2831 ...., usually written 2π. The symbol 2π is used both for shortness and because π is what is called an incommensurable number, *i.e.*, it cannot be completely represented by any decimal. It follows that the ratio of any given fraction of the circumference to the radius is also constant for all circles. Thus in Fig. 16,

$$\frac{\textit{length of arc } a_1}{r_1} = \frac{\textit{length of arc } a_2}{r_2}$$

$$= \text{constant for all circles}$$

the magnitude of the constant depending only on the angle θ. The ratio *arc/rad.* is therefore a natural measure of the angle and is in fact called the circular measure of the angle. Unit angle on this basis will be that for which

$$arc/rad. = 1$$

i.e., the angle subtended by an arc formed by bending the radius round the circumference. This angle is called one radian, and all angles in this system are expressed in terms of radians. Thus an angle 1.3, *i.e.*, 1.3 radians, is one subtended by an arc 1.3 times the radius in length.

The relation between the two sets of units is obvious, for half the circumference subtends 180°, and the ratio of this arc to the

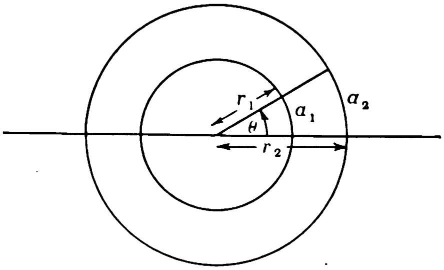

Fig. 16.

radius is as shown above, π, or 3·14159 ...., so that

$$180° = \pi \text{ radians},$$

which gives 57° 17′ 44·8″ as 1 radian. This is a cumbersome sort of relationship, but conversion is very rarely called for so it does not really matter. In general terms we have

$$\theta \text{ radians} = \left(\frac{180}{\pi}\,\theta\right)^\circ$$

A right angle is clearly $\pi/2$ radians, and the angles of a right-angled triangle can therefore be expressed in circular measure as $\pi/2$, θ, and $(\pi/2-\theta)$. Complementary angles (Sect. 2) are defined by

$$\theta + \theta' = \pi$$

and in practice the definition is extended to the case in which either of these angles is numerically greater than π, the other being correspondingly negative. In the familiar group of symbols *sin* $2\pi ft$ or *sin* ωt, where $\omega = 2\pi f$ (f being the frequency in cycles per second), ωt is an angle which increases at the rate ω, or $2\pi f$, *radians* per second.

9. (A) Area.

Area, or amount of surface, is a fundamental conception or thing of its own kind, which cannot be described in terms of anything else, as one soon discovers by trying to do so. Like all the fundamental physical quantities, its magnitude can only be expressed in terms of itself, *i.e.*, in terms of its own unit. Thus an area of ten units means an area having ten times as much surface as some area which it is has been agreed to call a unit area. Humanity has always been vitally concerned with area and a multiplicity of practical units has arisen in consequence, but they all have this feature in common—they are expressed in terms of the amount of surface of a square having a side of specified length, and for this reason they nearly all bear names, such as square mile, square centimetre, etc., which indicate the length of the side of the square. This choice of the unit shape is quite arbitrary—a circle of specified radius would serve the same purpose, but the accepted shape has the advantage that the area of a rectangle of sides a and b units of length is arrived at by the simplest possible calculation on this system. It is in fact ab units of area, as can easily be demonstrated by a little simple drawing, the unit of area being the square unit of length, whatever that may be. This, however, must not be taken to mean that " area is length multiplied by length " a statement which is completely unintelligible except as a conveniently abbreviated expression of the ideas which have just been described. (Compare this with the discussion in Part I on the physical aspect of multiplication.)

(B) Area of a Triangle.

Referring to Fig. 17, the area of the triangle ABC is $\frac{1}{2}ah$ where a is the length of the side BC. This can be demonstrated by completing the rectangles $EBDA$, $AFCD$. It can be shown, as in Sect. 5, that the lines AB, AC divide these rectangles into equal triangles, whence the above result follows.

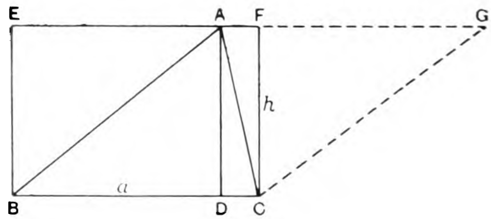

Fig. 17.

(C) Area of a Parallelogram.

In a similar manner it can be shown that the area of the parallelogram $ABCG$ is ah, for the diagonal AC divides it into two equal triangles.

(D) Area of a Circle.

Referring to Fig. 15, the area of each of the isosceles triangles into which the polygon is divided is $\frac{1}{2}bh$, so that the area of the whole polygon is $\frac{1}{2}nbh$. If the number of sides is increased indefinitely the figure becomes a circle, nb becoming the circumference, and h the radius. The area of the circle is therefore half the product of the length of the circumference and that of the radius. As already shown, the circumference is 2π times the radius, so that the area of the circle is $\frac{1}{2}(2\pi r)r$, *i.e.*, πr^2.

10. Vectors.

The idea " vector " is still hedged about with that vague apprehension and dislike that attaches to the unfamiliar; but the shyness, if it exists, must be fought down, for one cannot get far in electrical theory nowadays without it. The trouble is that although the essential idea itself is simple enough, its application calls for new habits of thought, a new mental technique. That means hard thinking, and hard thinking is the hardest of hard work. The technique, however, is worth all it costs in that way, and there can be no doubt that the vector

notation will play a large and increasing part in the mathematics and mathematical physics of the future. Even to-day it is unusual to find any analysis of alternating current circuit problems which is not expressed in terms of the symbol "j", and that symbol, as the following sections will show, is very intimately connected with the vector idea, though it is admittedly open to more than one interpretation (and a few misinterpretations).

It was pointed out in Sect. 2 that a single straight line in an infinite plane cannot in any useful sense of the word be said to possess direction, for direction is essentially a relation to some other straight line. We will therefore take as the domain of our present thinking an infinite plane and an infinite line in that plane. By the direction of any other

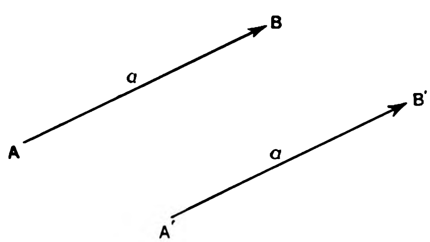

Fig. 18.

line in the plane will then be meant its direction relative to this given line. For practical purposes, the infinite plane can be taken as that of the paper one is writing on, and the reference line can be any line parallel to the bottom edge of the paper.

On this understanding any line in the plane of the paper will have direction, and any finite segment of the line will have both magnitude and direction. The name "vector" is given to any line regarded in this way as a combination of magnitude and direction. In general, any physical quantity whatever which possesses both magnitude and direction is called a vector quantity. Thus velocity, force, acceleration, etc., are vector quantities, and as such are capable of representation by means of vectors (not necessarily co-planar in any given system). Most of the quantities with which physics, and more particularly electricity, is concerned are of this character, whence the fundamental importance of the vector idea and of its technique. As distinct from a vector quantity, any quantity which has magnitude only is called a scalar quantity, or, shortly, a scalar. Density, temperature, energy, etc., are examples. The distinction is well marked in the case of weight and mass. The latter is a scalar, and the former, being the gravitational force associated with the mass, is a vector.

For the present, however, we shall not be concerned with vector quantities in general, but simply with the co-planar line vectors defined as above. It should be noted that no mention is made of position in the definition. Position plays a secondary part in vector analysis, and where it does enter into any given problem it will arise as a consequence of the other two attributes or will be otherwise specified. In general any two lines such as AB, $A'B'$, in Fig. 18, which are equal in magnitude and direction (the latter being indicated by an arrow head as shown) are vectorially identical. Following a well-established typographical practice, a line of length a will be printed in bold face type ($\mathbf{a}$) if it is being considered as a vector. Alternatively, $\overrightarrow{AB}$ will be taken to mean the line AB considered as a vector. The magnitude of any given vector $\mathbf{a}$ will be indicated either by using the same letter in ordinary type, or by $|\mathbf{a}|$.

(B) The Addition of Vectors.

A vector can be regarded as a displacement or step of specified amount and direction. The obvious interpretation of the addition of two vectors is the combination of the two displacements as shown in Fig. 19, the *sum*,

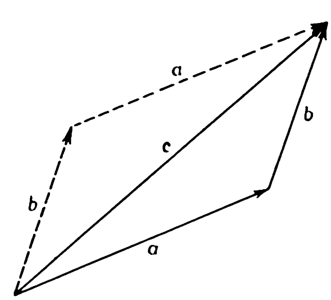

Fig. 19.

as distinct from the *process* of addition, being the single displacement which has the same total effect as the two displacements made in succession. Thus the sum of $\mathbf{a}$ and $\mathbf{b}$ is $\mathbf{c}$. From the properties of a parallelogram it

follows that $\mathbf{b} + \mathbf{a}$, shown by the dotted lines in Fig. 19, is the same as $\mathbf{a} + \mathbf{b}$, so that the process of addition of vectors obeys the commutative law, which brings it into line with the same process in ordinary algebra. The extension of the above, and of the commutative law, to the addition of any number of vectors is obvious. Notice that in general

$$|\mathbf{a}+\mathbf{b}| < |\mathbf{a}| + |\mathbf{b}|$$

which is Euclid's proposition about two sides of a triangle being greater than the third.

(C) Vector Interpretation of the Negative Sign.

As far as possible the symbolism of vector algebra will be made analogous to that of scalar algebra. Since therefore

$$a + (-a) = 0$$

in scalar algebra, let us use the same form vectorially and interpret $(-a)$, at present undefined, to suit this condition. If

$$\mathbf{a} + (-\mathbf{a}) = 0$$

then $-\mathbf{a}$ is a displacement which cancels the displacement $\mathbf{a}$, *i.e.*, $-\mathbf{a}$ is a vector of the same magnitude as $\mathbf{a}$ but opposite to it in direction. The subtraction of vectors then becomes an operation of essentially the same character as addition, for

$$\mathbf{a} - \mathbf{b} = \mathbf{a} + (-\mathbf{b})$$

The process is illustrated in Fig. 20. Notice that $\mathbf{a}+\mathbf{b}$ and $\mathbf{a}-\mathbf{b}$ are the diagonals of a parallelogram having $\mathbf{a}$ and $\mathbf{b}$ as sides.

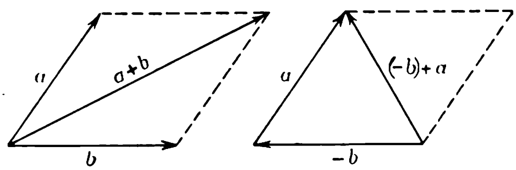

Fig. 20.

(D) The Multiplication of a Vector by a Number.

By analogy with the corresponding scalar operation

$\mathbf{a}+\mathbf{a}+\mathbf{a}+\mathbf{a}+$ etc. . . . . . . n terms

will be written $\mathbf{a}\times n$, or more conveniently $n\mathbf{a}$. Thus $n\mathbf{a}$ is a vector of the same direction as $\mathbf{a}$ but n times as long.

(E) The Idea of Operator and Operand.

The group $n\mathbf{a}$ can be regarded as symbolising a definite operation on the vector $\mathbf{a}$, which in this relation can be called the "operand." If n is a positive number or fraction, the operation consists of the multiplication of the magnitude of $\mathbf{a}$ by n without changing its direction. If n is a negative number or fraction, say, $-m$ where m is positive, then $n\mathbf{a}$ represents the somewhat more elaborate operation of multiplying the magnitude of $\mathbf{a}$ by m and reversing its direction. Regarded in this way, the symbol n is called an "operator." It is an essential feature of an operator that its effect shall be independent of its operand, *i.e.*, the relation of $n\mathbf{a}$ to $\mathbf{a}$ does not depend in any way on $\mathbf{a}$. This idea is more than a mere pedantic elaboration of terminology. Other forms of operator, which play a very large part in alternating current theory, will be introduced in later sections.

(F) Unit Vectors.

A unit vector is a vector of unit length. It follows from paras. (D) and (E) above that any vector whatever can be expressed in terms of a positive or negative number and some unit vector. Thus the vector $\mathbf{a}$ can be expressed in the form $a\,\mathbf{a}_1$, where $\mathbf{a}_1$ is the unit vector in the direction of $\mathbf{a}$. Thus $m\mathbf{a}_1$ and $n\mathbf{a}_1$ are vectors of magnitudes m and n and of the same or opposite direction according as m and n are of the same or opposite sign. Notice that

$$m\mathbf{a}_1+n\mathbf{a}_1=(m+n)\mathbf{a}_1$$

In all that follows the symbol ν will be used for the unit vector in the direction of the bottom edge of the page from left to right.

11. The Scalar Product of Vectors.

In the arithmetical sense of the term, the multiplication of two vectors is not an intelligible process at all, but there is a quantity which involves two vectors in a manner similar to multiplication, and to this the name scalar product is given. It is defined in this way. The scalar product of two vectors $\mathbf{a}$ and $\mathbf{b}$ is the scalar quantity $ab \cos\theta$, a and b being the magnitudes of the vectors and θ the angle between their positive directions. It is written $\mathbf{a}\cdot\mathbf{b}$, so we have

$$\mathbf{a}\cdot\mathbf{b}=ab\cos\theta$$

The character of this product will be made clear by an inspection of Fig. 21(A). If BP

is drawn perpendicular to OA, then

$$\frac{OP}{OB} = \cos\,\theta$$

i.e., $OP = OB \cos\theta = a \cos\theta$

so that $\mathbf{a}\cdot\mathbf{b} = ab \cos\theta = OA{\cdot}OP$

The scalar product is thus the product of the magnitude of one vector and of the "projection" of the other on it.

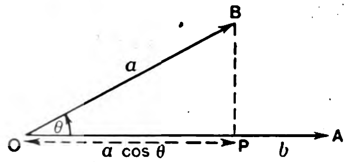

Fig. 21 (A).

Notice that a scalar product has sign as well as magnitude. This is because $\cos\theta$ has sign. Thus the scalar product of the vectors **a** and **b** shown in Fig. 21 (B) will be a negative quantity, for in this case θ is in the second quadrant and its cosine is therefore negative.

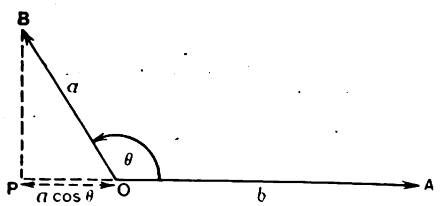

Fig. 21 (B).

Notice further that there is no question of extending this notation to more than two vectors. $\mathbf{a}\cdot\mathbf{b}$ is a scalar quantity, so there is no scalar product of $(\mathbf{a}\cdot\mathbf{b})$ and a third vector **c**.

This conception of scalar product may at first sight seem rather arbitrary, but it has as a matter of fact a very definite physical significance. To take one of the many instances of its physical interpretation, if **a** represents the displacement of a body under the action of a force represented by the vector **b**, then $\mathbf{a}\cdot\mathbf{b}$ is the work done by the force on the body. Another application of a rather different character is of particular interest to wireless amateurs. Let **e** be a vector of magnitude $\hat{e}$, making with ν an angle θ. Further, suppose that θ is proportional to time, increasing at ω radians per second, its magnitude being ϕ when $t = 0$,

i.e., $\theta = \omega t + \phi$

Then $\mathbf{e}{\cdot}\nu = \hat{e} \cos(\omega t + \phi)$

Thus a sine wave of E.M.F. can be represented as the scalar product with a fixed unit vector of another vector of constant length rotating with constant angular velocity (ω).

It will now be shown that scalar multiplication obeys the same formal laws as ordinary multiplication. It follows from the definition that

$$\mathbf{a}\cdot\mathbf{b} = \mathbf{b}\cdot\mathbf{a}$$

so that a scalar product obeys the law of commutation.

Further it is easy to show that scalar multiplication of vectors obeys the distributive law, i.e.,

$$\mathbf{c}\cdot(\mathbf{a}+\mathbf{b}) = (\mathbf{a}+\mathbf{b})\cdot\mathbf{c} = \mathbf{a}\cdot\mathbf{c} + \mathbf{b}\cdot\mathbf{c}$$

The demonstration is illustrated in Fig. 22. We have

$$\begin{aligned}(\mathbf{a}+\mathbf{b})\cdot\mathbf{c} &= OQ \times OC\\ &= (OP+PQ)\times OC\\ &= OP\times OC + PQ\times OC\\ &= \mathbf{a}\cdot\mathbf{c} + \mathbf{b}\cdot\mathbf{c}\end{aligned}$$

It follows directly from this that

$$(\mathbf{a}+\mathbf{b})\cdot(\mathbf{c}+\mathbf{d}) = \mathbf{a}\cdot\mathbf{c} + \mathbf{a}\cdot\mathbf{d} + \mathbf{b}\cdot\mathbf{c} + \mathbf{b}\cdot\mathbf{d}$$

and similarly for the scalar products of vectors expressed as the sums or differences of any number of component vectors. Operations of scalar multiplication of vectors can therefore be carried out in just the same way as the ordinary multiplication of similar number groups.

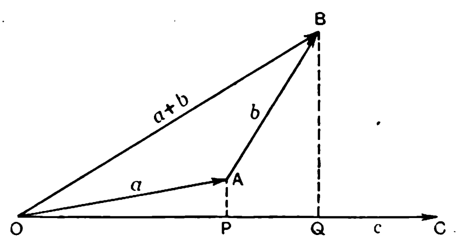

Fig. 22.

Two Important Special Cases.

(i) $\mathbf{a}\cdot\mathbf{a} = a \times a \times \cos 0 = a^2$

This can be written

$$\mathbf{a}^2 = a^2$$

Thus the scalar square of a vector is the square of its magnitude.

(*ii*) If $\mathbf{a}$ and $\mathbf{b}$ are perpendicular to each other, then

$$\mathbf{a}\cdot\mathbf{b}=a\times b\times \cos \pi/2=a\,b\times 0=0$$

The converse of this is also true with a reservation.

If $\qquad \mathbf{a}\cdot\mathbf{b}=ab\cos\theta=0$

then $\qquad a=0$

or $\qquad b=0$

or $\qquad \cos\theta=0$

i.e., $\qquad \mathbf{a}=0$

or $\qquad \mathbf{b}=0$

or the vectors are mutually perpendicular.

This will prove to have an important application to alternating current theory in the following form. Suppose that i_1, i_2, i_3, etc., be a number of alternating currents

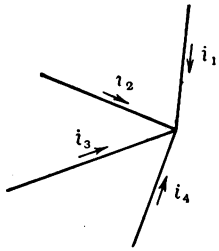

Fig. 23.

which meet at a branch point of a network of conductors as shown in Fig. 23. Then by Kirchhoff's first law, the sum

$$i_1+i_2+i_3+\text{etc.}=0$$

at every instant. Now as shown in above, each of these currents can be represented in the form $\mathbf{i}_1\cdot\nu$, $\mathbf{i}_2\cdot\nu$, etc., where $\mathbf{i}_1$, $\mathbf{i}_2$ are vectors of constant magnitude rotating with constant angular velocity. Therefore

$$\mathbf{i}_1\cdot\nu+\mathbf{i}_2\cdot\nu+\mathbf{i}_3\cdot\nu+\text{etc.}=0$$

i.e., $\qquad (\mathbf{i}_1+\mathbf{i}_2+\mathbf{i}_3+\text{etc.})\cdot\nu=0$

Therefore the vector $(\mathbf{i}_1+\mathbf{i}_2+\mathbf{i}_3+\text{etc.})$ is zero or else is perpendicular to ν at every instant. The second condition cannot be fulfilled at every instant, for the vectors are assumed to be rotating with constant angular velocity. Therefore

$$(\mathbf{i}_1+\mathbf{i}_2+\mathbf{i}_3+\text{etc.})=0$$

so that Kirchhoff's law applies not only to the instantaneous values of the currents which meet at a branch point, but also to the rotating vectors which, as described more fully later on, are used to represent these currents.

Examples.

1. Take 22/7 as a sufficiently close approximation for π. Find in degrees and minutes to the nearest minute

i. $1\frac{1}{21}$ radians.

ii. $\frac{1}{7}$ radian.

Find the magnitude in radians of

iii. 10°.

iv. 1260°.

2. Find the area of

i. A regular octagon with side 10 units in length.

ii. A sector of a circle or radius 5 cms., length of arc 10 cms.

3. If the unit of area were defined as that of a circle of unit radius, what would be the area of the figures described in (2) ?

4. The vectors $\mathbf{a}$ and $\mathbf{b}$ are of length 5 and 10 cms. respectively, and make with some other vector angles of 60° and 30° respectively.

Find graphically *i.* $|\mathbf{a}+\mathbf{b}|$; *ii.* $|\mathbf{a}-\mathbf{b}|$; *iii.* Calculate $\mathbf{a}\cdot\mathbf{b}$; *iv.* Measure the angle between $\mathbf{a}+\mathbf{b}$ and $\mathbf{a}-\mathbf{b}$, and calculate $(\mathbf{a}+\mathbf{b})\cdot(\mathbf{a}-\mathbf{b})$. Show by calculation *v.* $(\mathbf{a}+\mathbf{b})\cdot(\mathbf{a}-\mathbf{b})=\mathbf{a}^2-\mathbf{b}^2$;

vi. $(\mathbf{a}+\mathbf{b})^2=\mathbf{a}^2+2\mathbf{a}\cdot\mathbf{b}+\mathbf{b}^2$;

vii. $(\mathbf{a}-\mathbf{b})^2=\mathbf{a}^2-2\mathbf{a}\cdot\mathbf{b}+\mathbf{b}^2$

Answers to Examples in May Issue.

1. 80°.

2. Figure divides into five triangles. Therefore sum of internal angles is 5×2 right angles, minus the sum of the angles at the centre, *i.e.*, minus four right angles. Therefore sum is six right angles.

3. e is $4\frac{4}{9}$, f $5\frac{5}{9}$, both in inches.

5. $\tan 50^\circ=1.191$; $\sec 50^\circ=1.555$; $\operatorname{cosec} 50^\circ=1.305$; $\cot 50^\circ=.840$; $\sin 140^\circ=\sin(90+50)^\circ=.643$; $\cos 220^\circ=\cos(270-50)^\circ=-.766$; $\tan 320^\circ=\tan(270+50)^\circ=-.840$; $\tan -50^\circ=-1.191$; $\sin 40^\circ=\cos 50^\circ=.643$; $\sec -40^\circ=\sec 40^\circ=\operatorname{cosec} 50^\circ=1.305$.

$(\sin 50^\circ)^2+(\cos 50^\circ)^2=1.000$.

Self-Inductance of Straight Wires.

By R. M. Wilmotte, B.A.

(*Of the National Physical Laboratory.*)

THE design of an effective choke circuit for extra high frequencies of the order of 10^7 or 10^8 cycles per second and higher is one of growing importance and the common practice applicable to lower frequencies must be considerably modified as the frequency reaches these high values.

As the frequency rises, the effect of the self-capacity of the choke becomes of increasing importance, until at extra high frequencies it is necessary to space the wires forming the choke so that the distance between wires is never less than some 200 times the diameter of the wire, as will be seen below. When such spacing is kept throughout the design of a choke, one obtains the remarkable result, that the self-inductance of the choke is little affected by the way in which the wire is coiled. That is, if the choke is made of a given length of wire, it does not matter whether the wire is stretched out in a straight line or coiled in the ordinary way, the self-inductance will be nearly the same in both cases. The main requirement for large self-inductance is length and thinness of wire.

That the self-inductance of a wire is not very much affected by being coiled up may seem against common sense and an altogether improbable view, yet that this is so can be readily understood.

The self-inductance of a circuit is equal to the total magnetic flux (due to the current in the circuit) threading this circuit when a unit current is passing. Now the magnetic force at a point, due to a long length of wire carrying a current, is inversely proportional to the distance of that point from the wire. In the case of a very thin wire, the magnetic field at or near the surface of the wire will be very large and practically independent of the rest of the circuit, if the distances of all other parts of the circuit from the portion considered are large compared to the diameter of the wire.

In such a case, then, practically the whole of the flux linking the wire will be within a small imaginary cylinder surrounding the thin wire of the circuit. So long as this cylinder does not cut itself, the self-inductance of the circuit will be practically independent of its shape. This will, of course, hold, if the wire is very thin and the distance between the various parts of the circuits is large compared with the diameter of the wire.

In order to give quantitative basis to these conclusions, we shall deal with a few formulæ and put numbers into them, but before doing this, the meaning of the self-inductance of a straight wire must be explained. This point was raised in the Editorial of the January, 1926, number of the *E.W. & W.E.*, and it may be useful to explain the exact meaning and application of the terms.

The E.M.F. induced by a magnetic field in a wire is, by Faraday's law, proportional to the rate at which lines of force cut it. When the magnetic field is produced by a current in the wire itself, we obtain the idea of self-inductance, which is the total number of lines of force which collapse on to the current when this current is reduced from a value of one ampere to zero. Now, consider a small length of wire $A\ B$ and imagine that it is carrying a current of one ampere. In order to make this possible, we must suppose the circuit to be completed, but, since we are dealing only with the portion $A\ B$ of the circuit, we shall suppose that there is a mutual inductance M between $A\ B$ and the rest of the circuit, the value of M being dependent on the shape of the circuit outside $A\ B$.

If L_{AB} be the self-inductance of the portion, $A\ B$ and L that of the rest of the circuit, then the self-inductance L_0 of the whole circuit will be given by

$$L_0 = L_{AB} + L - 2M \quad .. \quad (1)$$

Now, consider the magnetic field produced by the current in the part $A\ B$ of the circuit (Fig. 1).

It is evident that we have cylindrical symmetry about the axis $A\ B$. Thus the

line of force through any point P will be a circle having $A\ B$ produced as axis. When the current in $A\ B$ is decreased how will this line of force move? The idea that it moves is purely arbitrary and is only to allow us to visualise the process. We can make it follow any path we like, such as the line $O\ P$ or $P\ R$, but having once decided on a definite path we must keep to it in all our calculations of self and mutual inductance.

Suppose we consider the line of force at P to collapse along the cone $O\ P$, we can calculate the total number of lines of force

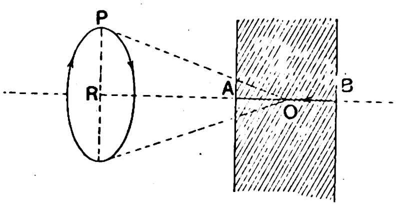

Fig. 1.

that collapse on to $A\ B$ when the current is reduced to zero. Unfortunately, this calculation leads us to the most unsatisfactory result that the self-inductance of the wire $A\ B$, according to this definition, is infinite, which is of very little practical use. We must try to look for a definition which will give a finite result. Such a definition is obtained by considering that these lines of force collapse radially along lines such as $P\ R$. According to this, only the lines of force which are in the area shown shaded will be effective in creating self-inductance, the rest of the field will collapse on $A\ B$ produced and this will not be a cause of creating an E.M.F. in $A\ B$.

It may seem definitely wrong to assume that part of the flux produced by the current in $A\ B$ is neglected as far as the self-inductance of $A\ B$ is concerned but this is not so, for $A\ B$ must be considered as part of a circuit and the flux, which we have neglected in considering $A\ B$, will, on collapsing on to $A\ B$ produced, cut other parts of the circuit and will therefore be included in the mutual inductance M between $A\ B$ and the rest of the circuit.

We thus see that the meaning of the self and mutual inductance of a portion of a circuit is dependent on the arbitrary notion, which we have regarding the motion of the lines of force, but, having once fixed our ideas, the meaning becomes quite definite, though it may well be argued that, owing to the special meaning applied, the terms of self and mutual inductance used in this connection are misleading.

However, since the terms are now fairly universally used and the reader does, or at any rate should, now understand the special meaning implied, I will continue to use them, hoping that my previous explanation will be sufficient in preventing errors.

I shall give a few formulæ, which refer to wires of circular cross section, and for lengths which are large compared to the radius of the wires. The values of L and M in the following formulæ are in microhenries, all linear dimensions being in cms.

The self-inductance L of wire of length l and radius r for direct current is given by

$$L=2l\left[\log_e(2l/r)-1+\frac{\mu}{4}\right]\times 10^{-3} \quad .. \quad (2)$$

where the permeability of the substance of the wire is μ and that of the dielectric is unity.

For H.F. current the self-inductance is given by

$$L=2l\left[\log_e(2l/r)-1\right]\times 10^{-3} \quad .. \quad (3)$$

The difference between equations (2) and (3) is caused by the difference of magnetic field within the wire in two cases. Equation (2) refers to uniform distribution of current across the section of the wire, which occurs when the wire is thin and the frequency not too high, while the equation (3) gives the case when the magnetic field within the wire is zero, that is, all the current flows on the surface of the wire. This occurs in thick wires and at very high frequencies. It will be seen that the difference between equations (2) and (3) will in general be quite small.

The mutual inductance between two equal parallel wires of length l, which is large compared with their distance d apart, is given by

$$M=2l\left[\log_e(2l/d)-1+\frac{d}{l}\right]\times 10^{-3} \quad .. \quad (4)$$

The self-inductance of a circuit, made of two long, equal, parallel wires distant d apart, is obtained from equations (3) and (4) giving

$$L'=2L-2M$$
$$=4l\left[\log_e(d/r)+\frac{\mu}{4}\right]\times 10^{-3} \quad .. \quad (5)$$

The mutual inductance between two contiguous linear conductors of lengths l_1 and l_2 in the same straight line is given by

$$M=\left[l_1 log_e\left(\frac{l_1+l_2}{l_1}\right)+l_2 log_e\left(\frac{l_1+l_2}{l_2}\right)\right]\times 10^{-3} \quad (6)$$

The mutual inductance between two parallel linear conductors of lengths l_1 and l_2 distant d apart (Fig. 2) is given by

$$M=\left[l_1 \, log_e\left\{\frac{l_1+l_2+\sqrt{(l_1+l_2)^2+d^2}}{l_1+\sqrt{l_1^2+d^2}}\right\} + l_2 \, log_e\left\{\frac{l_1+l_2+\sqrt{(l_1+l_2)^2+d^2}}{l_2+\sqrt{l_2^2+d^2}}\right\} + \sqrt{(l_1+l_2)+d^2}-\sqrt{l_1^2+d^2}-\sqrt{l_2^2+d^2}\right] \times 10^{-3} \quad .. \quad (7)$$

When d is small, this reduces to equation (6).

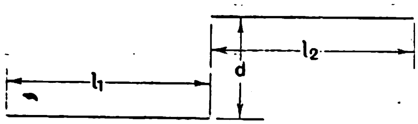

Fig. 2.

It should be noticed that the mutual inductance between two perpendicular wires is zero.

From these formulæ, the self and mutual inductances of any circuits, the sides of which are parallel and perpendicular to each other, can be calculated.

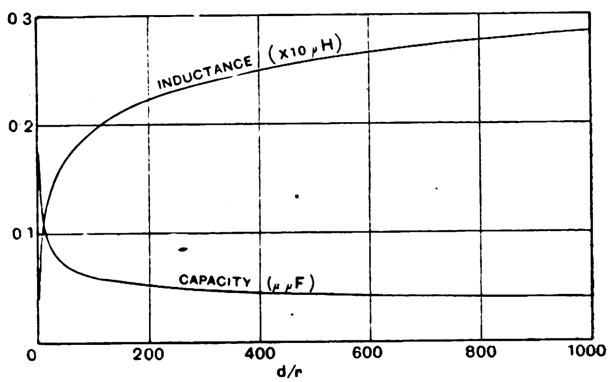

Fig. 3.

Now, to return to our original inquiry on chokes, we shall require one more formula giving the capacity between two long parallel wires of radius r distant d apart (d is large compared to r),

$$C=\frac{l}{3.6 \, log_e \, (d/r)} \mu\mu F \quad .. \quad (8)$$

From equations (4) and (8) the following table has been calculated for the constants per unit length of two parallel wires.

d/r	Self-inductance (microhenries.)	Capacity. ($\mu\mu$F.)
5	0.0075	0.179
10	0.0102	0.121
20	0.0130	0.093
50	0.0167	0.071
100	0.0194	0.060
250	0.0231	0.050
500	0.0259	0.045
750	0.0275	0.042
1,000	0.0286	0.041
5,000	0.0331	0.033
10,000	0.0378	0.030

These values are plotted in Fig. 3. It will be at once evident how quickly the capacity decreases as the ratio (d/r) increases and reaches an almost constant value. At the same time, the self-inductance is rapidly increasing to a sensibly constant value also.

Now at extra high frequencies, it is all-important that the self-capacity should be low. A capacity of $3\mu\mu$F, at a wavelength of 15 metres, has an impedance of approximately 2,500 ohms. It is not much use having a coil of very large impedance if it is to be shunted by 2,500 ohms. It becomes evident that we must reduce the self-capacity first of all and consider the self-inductance afterwards.

The curve of Fig. 3 shows that d/r must be large, that is the distance of various parts of the circuit must be some 200 times the diameter of the wire, and to do this within a reasonable space we must use thin wire such as 47 S.W.G.

When d/r is large, the mutual inductance between the various parts of the circuit will be small (see above formulæ) and the inductance of the circuit will be nearly equal to the self-inductance given by equations (2) or (3), in which l is the total length of wire irrespective of its shape.

At very high frequencies corresponding to wavelengths of a few metres it will be found very convenient to use simply a straight length of number 47 S.W.G. wire as choke. This is often quite sufficient and at the same time keeps the terminals far apart, which is important, for it must be remembered that the choke may become quite ineffective, if it has large terminals close together at its ends, owing to the capacity between them.

At longer wavelengths, between 10 metres and 100 metres, the spacing between wires need not be so large.

A single layer solenoid of number 47 S.W.G., having the distance between its turns about 20 times the radius of the wire, will be found to produce a very good choke. The above formulæ will not hold, however, for this case, and we have to return to the simple formula which applies with very good accuracy for this spacing. The formula is

$$L = \frac{\pi^2 d^2 n^2}{l \times 10^3} \times k \text{ microhenries}$$

where d is the diameter of the solenoid, n the number of turns and l the length.

k is an end effect correction factor depending on the ratio of the length to the diameter of the solenoid. Its value is given by the graph Fig. 4.

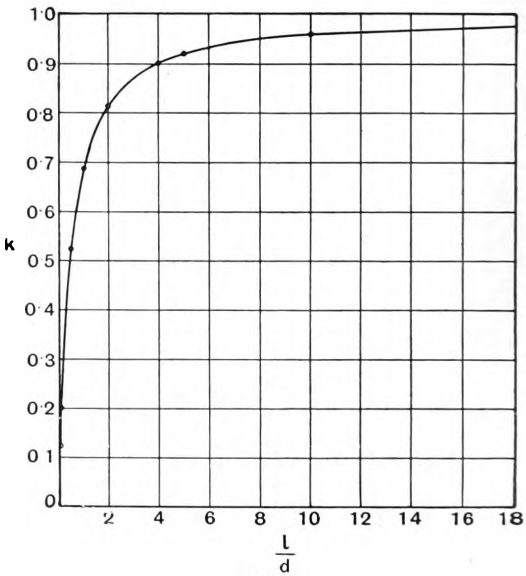

Fig. 4.

Wireless Transmitting Valves.

The meeting of the I.E.E. Wireless Section on 4th May was devoted to a wide discussion of transmitting valves. Three papers were read, each dealing with the type of valve stated below, while a general discussion on the whole subject followed the reading of the papers. Abstracts of the individual papers and of the general discussion are given below.

The Holweck Demountable Type Valve.

By C. F. Elwell, M.I.E.E.

ABSTRACT.

THE paper first describes briefly the Holweck molecular pump, used in conjunction with the demountable valve. It consists (Fig. 1)* of a smooth light cylinder

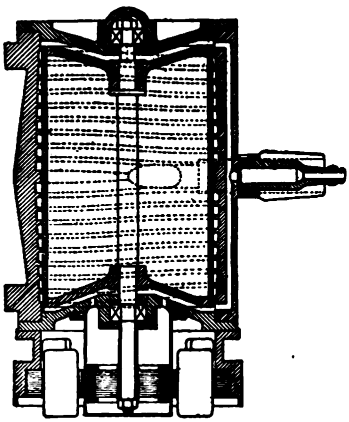

Fig. 1.

mounted on ball bearings inside and very close to a heavy casting upon the inside of which a 7-turn right- and left-hand spiral groove of diminishing cross section has been cut. The cylinder is driven at 4,500 r.p.m. by means of a rotating field, rendering it unnecessary to bring the shafts supporting the rotating portion through the body of the pump. A small passage in the body serves as a connection to a rough vacuum pump, and a large orifice connecting the two spiral grooves serves as a connection to the vessel (*i.e.*, valve) to be evacuated. The cylinder thus revolves in the rough vacuum, so that less than 10 watts is necessary to drive it at the high speed stated. When the current is cut off the cylinder continues to rotate for upwards of an hour. In practice the pump has proved capable of maintaining the vacuum on demountable valves with 8,000 volts on the anode.

The valve, which is mounted directly on the top of the pump, is shown in Figs. 2 and 3. It comprises :—

1. Lower glass or quartz insulating piece for connecting the valve to the pump.

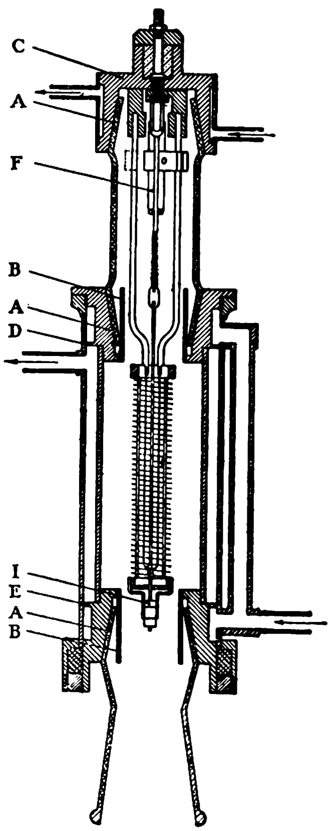

Fig. 2.

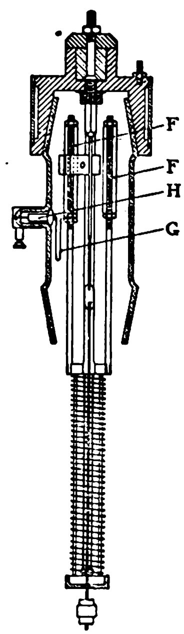

Fig. 3.

* The authors' original figure numbers are adhered to throughout these abstracts.

2. Water-cooled anode.

3. Upper glass insulating piece with grid connections.

4. Water-cooled head carrying grid and filament.

These valves are made in 10kW and 30kW sizes and a sufficient number is now in service to warrant their serious consideration as a rival to the sealed-in variety. Against the need for a pumping system must be balanced the advantage of being able to renew the filament at the cost of a few pence.

Each of the types is capable of considerable overload and it is stated that on trial one of the 30kW valves took 100kW. This suggests the feasibility of making single units of 100kW, which in turn might only be stepping stones to the building of single units capable of handling 200, 500 or 1,000kW.

It is also stated that at the Malmaison Station a 10kW valve has been used down to 37.5 metres, signals of strength 7 being received in Shanghai, and of strength 9 in S. America.

Silica Valves in Wireless Telegraphy.

By H. Morris Airey, C.B.E., M.Sc., M.I.E.E., G. Shearing, B.Sc., M.I.E.E., and H. G. Hughes, M.Sc.

ABSTRACT.

THIS paper deals with silica valves as used in British Naval wireless transmitters.

In discussing the properties of silica as an envelope for high-power valves, the authors point out that it has the advantages of: (i.) very high softening point; (ii.) low coefficient of thermal expansion; (iii.) ease of manufacture and of opening for repair; (iv.) high insulating properties; (v.) high diathermancy; (vi.) low dielectric loss at high frequencies.

Silica valves are divided into two classes according to the method of cooling the anode:—

(A) Valves in which the heat is removed by radiation through the silica envelope.

(B) Valves in which the heat is removed by direct contact of the anodes with a cooling fluid.

An important point in the silica valve is the seal through which electrical contact is effected. The basis of the seal is a lead plug in a short length of thick-walled silica tubing. The lead is melted *in vacuo* in the silica tube, under which conditions the molten lead adheres firmly to the silica, forming a vacuum tight joint. For ratings up to 50 amperes the conductors to the interior and exterior are embedded in the lead plug. For larger seals, up to 100 amperes, the plug is modified so that the current is conveyed independently of it. The two types of seal are shown in Figs. 1A and 1B.

The silica envelope consists of a cylindrical body with domes welded on the two ends.

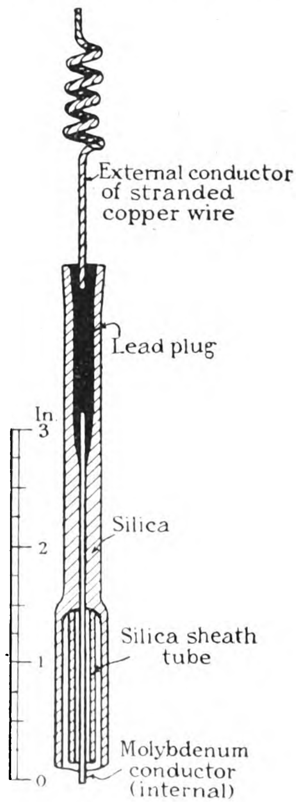

Fig. 1A.

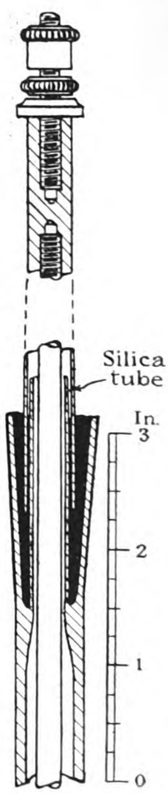

Fig. 1B.

The electrode seal tubes are fused into the domes in a direction which is usually parallel to the axis of the cylinder. This form is

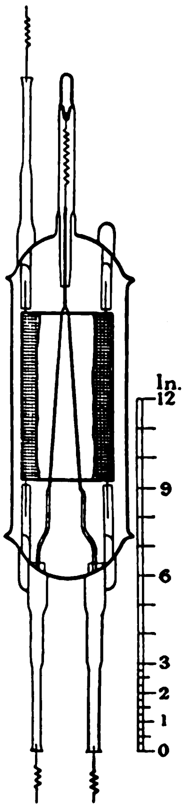

Fig. 2.

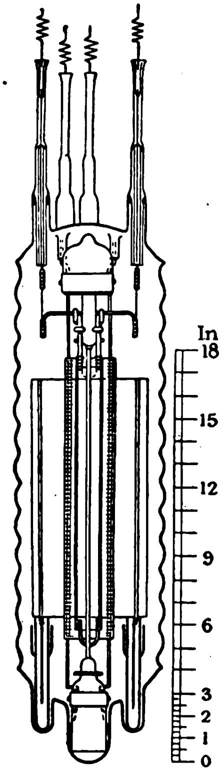

Fig. 5.

convenient for baking processes during evacuation.

Typical constructions are illustrated in Figs. 2 and 5. The grid usually has a framework of molybdenum and a spiral or mesh of either tungsten or molybdenum. The anode of the radiation types is now of cylindrical form of molybdenum strip, woven basket fashion.

The construction of naval silica valves is such that they can be readily repaired. One of the domes may be cut off the body by means of a carborundum wheel and the electrode system removed. Any reconstruction necessary can thus usually be effected at a fraction of the cost of a new valve.

For sets of power up to the order of 15kW the heat energy from the anodes is dissipated by radiation from the bulb. For higher powers provision has been made for cooling by a circulatory system.

A method of external cooling is illustrated in Fig. 6. This employs a double-walled cylinder containing the circulating water and surrounding the valve, which is thus not in direct contact with the fluid. The seals of the valve are on the top dome and are air-cooled. In another method of external cooling the valve is totally immersed in a tank containing oil, which is circulated by a pump through a radiator system.

The introduction of the type of seal in which the conductor is independent of the lead plug has enabled valves to be constructed in which the anode is an internal spiral tube of metal as shown in Fig. 7.

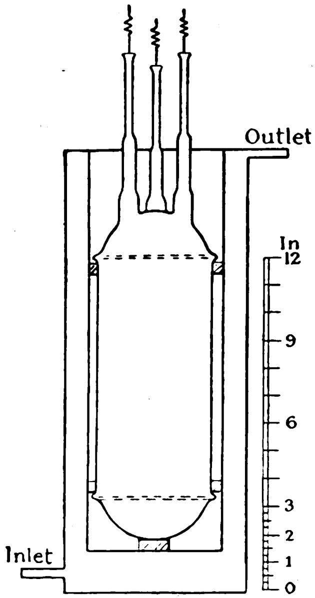

Fig. 6.

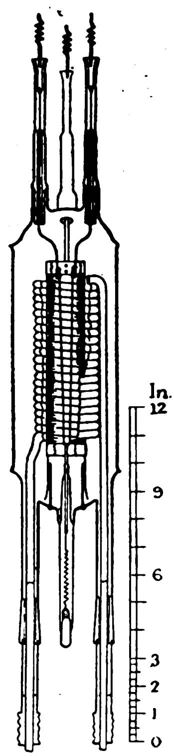

Fig. 7.

The cooling of the anode is effected by the circulation of oil or water through this tube. This arrangement permits the use of smaller silica envelopes than for the equivalent power rating of the radiation type of valve. This type of valve is, at present,

in its development stage, and none has been standardised for production.

Failure of the majority of defective valves has been due to burnt-out filaments, 90 per cent. having been known to fail from this cause. For burnt-out filaments the repair cost is from 15 to 20 per cent. of initial cost, while the average cost of repairs for all kinds of defects is from 20 to 25 per cent. of the initial cost of the valve.

Cooled Anode Valves and Lives of Transmitting Valves.

By W. J. Picken, A.M.I.E.E.

ABSTRACT.

This paper is of much greater length than the other two. The first part of the paper deals with cooled anode valves, and the latter part with the lives of transmitting valves; the life data quoted by the author being mostly for radiation-cooled glass valves.

The term "cooled anode" is used to cover valves in which the anode forms part of the envelope and is capable of being cooled by water, oil or other liquid applied directly to it.

In the introductory paragraphs the author refers to the advantages of the cooled anode type, particularly in the considerable increase of power which they have rendered possible. He then proceeds to describe valves of this type made for Marconi's Wireless Telegraph Co., Ltd., by the M.O. Valve Co., Ltd.

The types of valve described are:—

*Cooled Anode Transmitting Valves, C.A.T.*1, *C.A.T.*2, *C.A.T.*5.

*Cooled Anode Modulating or Absorbing Valves, C.A.M.*1, *C.A.M.*2, *C.A.M.*3.

*Cooled Anode Rectifying Valves, C.A.R.*1, *C.A.R.*2, *C.A.R.*3.

The first valve of the type developed was C.A.T.1 shown in Fig. 1. The anode is of copper tube 5 cm. diameter and 23 cm. long. On one end is brazed a ring of nickel iron on which a large glass cylinder of 7 c.m. diameter is sealed. By the choice of a suitable nickel-iron alloy it is possible to obtain the same coefficient of expansion as for glass. Details of construction, evacuation, etc., are given, and processes of manufacture were illustrated by photographic slides displayed during the reading of the paper. This valve is capable of standing a dead-loss test of 7.5kW at 15,000 volts without

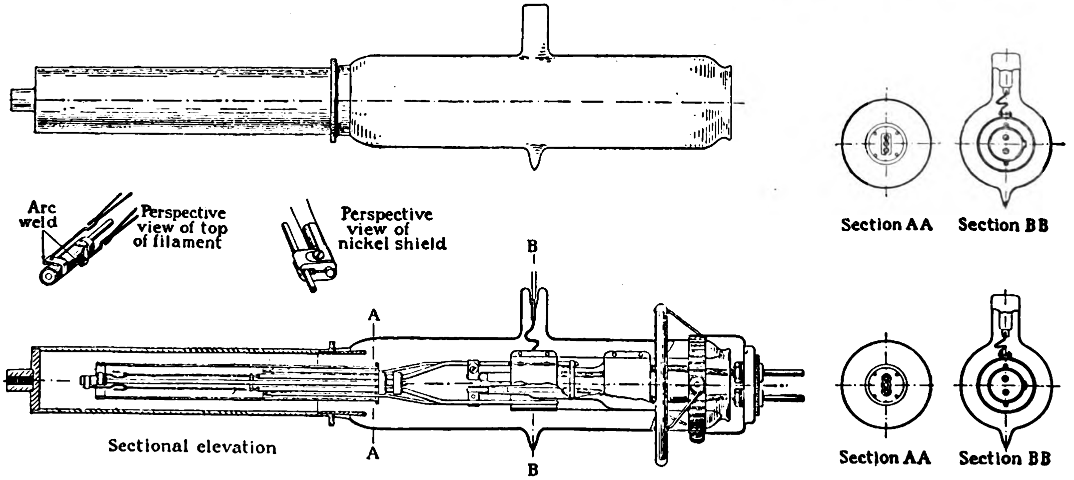

Fig. 1.

impairing the vacuum. On oscillatory tests it has been taken up to an input of 30kW at 15,000 volts. The general practice of the Marconi Co. is to rate valves conservatively so that the "life expectation" may be high. The C.A.T.1 valve is therefore usually rated at 10-15kW input at 10-12,000 volts, with a maximum loss of about 3kW in the anode when used normally as a high frequency magnifier or self oscillator.

consistent with good characteristics. The interelectrode insulation is increased, and the construction allows easy fitting to all electrodes of conductors capable of standing heavy high frequency currents with very low I^2R losses. Oil is sometimes used instead of water for cooling this valve on short wavelengths in order to avoid dielectric losses in the water. Inputs of 10kW at about 15 metres wavelength are handled

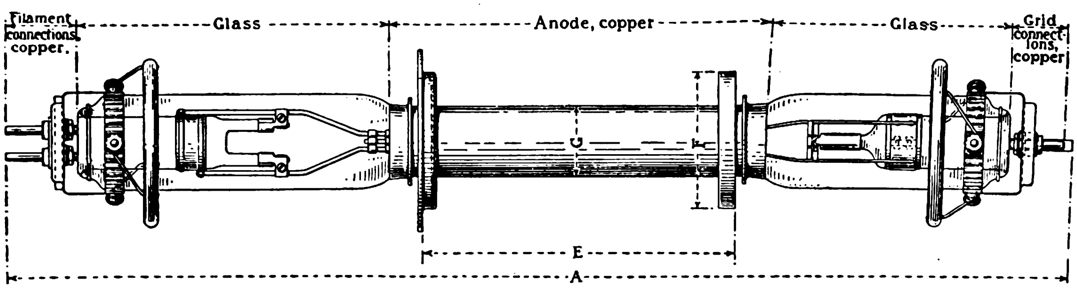

Fig. 9.

by this type acting as a high frequency magnifier.

The author then briefly discusses the conditions under which valves are operated. It is pointed out that the ratio of peak space current (*i.e.*, the peak value of instantaneous anode and grid currents) to mean anode current is generally taken as 5 to 1. Thus for 10kW input at 10kV the mean anode current is 1 ampere, and 5 amperes total emission is required. In telephony the conditions are more arduous. With a modulation of 80 per cent., the anode voltage swings at audio frequency up to 18kV when the anode current is 1.8 amperes. Taking a 5 to 1 ratio as before a total emission of 9 amperes is required. The H.F. peak potentials will be of the order of 34,000 volts. Protective devices in the form of Corona rings, etc., are therefore incorporated.

General methods of applying the water cooling are then discussed, especially with reference to hardness of the water.

C.A.T.5 valve, which is then described, is of similar general design to C.A.T.1, but rated at 15 to 20kW at anode voltages up to 12kV.

The C.A.T.2 valve, next described, and shown in Fig. 9, was produced especially for use on short wave beam transmitters. The grid and filament are mounted on glass-work at opposite ends of the anode, thus giving the minimum grid-filament capacity

Amongst the modulators, Type C.A.M.1 is similar to C.A.T.1 but with an open spiral grid, giving a low anode impedance and amplification factor to avoid distortion.

Type C.A.M.2 is particularly suitable for use as an absorption modulator for keying a wireless telegraph transmitter. The system is shown in Fig. 14. During spacing intervals a positive potential is applied to the "absorber" grid. Anode current flows, causing current to traverse the resistance X, which absorbs power during the "spacing" period. On "masking" a suitable negative potential is applied to the grid, reducing the anode current to zero and no power is absorbed in the resistance. This lessens the fluctuations of load and consequent voltage variations which would otherwise occur. A convenient method of keying is obtained by simultaneously varying the anode voltage of the "drive" at Y.

For use as an absorber it is necessary that (1) with suitable negative potential, the grid should completely cut off anode current at the highest anode voltages, and (2) the grid must be capable of standing for long periods losses incurred by a relatively high positive grid voltage at the same time as the anode voltage is at a maximum. To keep the

requisite grid voltages at reasonable values, the amplification factor is 25.

Type C.A.M.3 is a modulating valve of greater power than C.A.M.1, generally approximating to C.A.T.5 in physical dimensions.

The simplest type of rectifier valve is similar to a transmitting valve with the grid omitted. Thus C.A.R.1 resembles almost exactly C.A.T.1. It is capable of handling 1 ampere at 10,000 volts when used as in Fig. 14.

In full wave rectification, during the non-conductive half cycle the valve has almost twice the A.C. peak potential difference between anode and filament. This powerful field tends to bow the filament, which centre of the filament allows the return anode current to be led into the filament at several points. The construction has led to a valve of only 150 ohms anode/filament resistance.

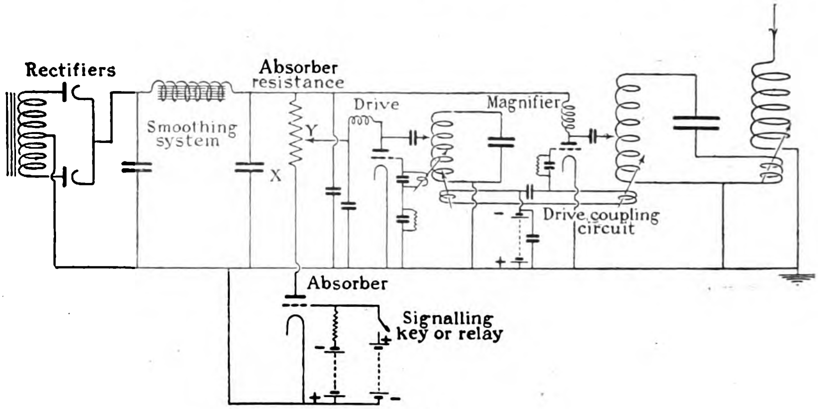

Fig. 14.

Type C.A.R.3 is of similar construction capable of supplying A.C. voltages up to 25,000, and has a total emission of 10 amperes.

A variety of the valves described were on exhibition at the meeting.

The latter part of the paper deals with the lives of transmitting valves. The factors governing valve life are given as :—

1. Diameter of filament.
2. Effective area of filament.
3. Total emission required of filament.

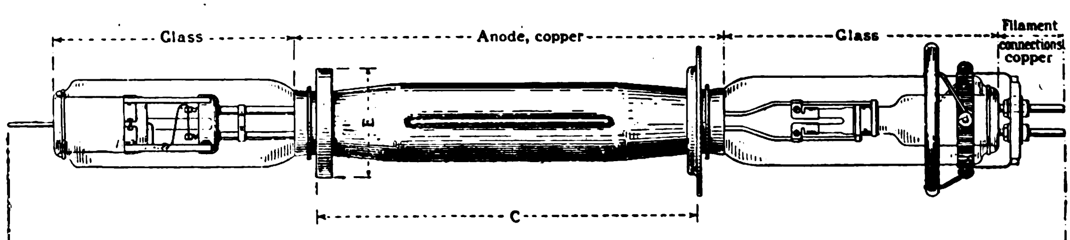

Fig. 23.

difficulty is overcome in the C.A.R.2 type (Fig. 23). The anode is compressed into two cylindrical upper chambers, as shown, with one leg of the filament in each. This "binocular" construction makes it possible to reduce the anode diameter without fear of filament distortion. A connection to the

Unless the filament is very short, when end-cooling becomes serious, the life of a filament increases in direct proportion to the increase of its diameter. The tendency is therefore towards filaments taking heavy currents at low voltages.

Fig. 26 shows the variation of the life of

a filament and the total emission with temperature and the corresponding changes in (1) watts per ampere emission, (2) filament voltage and (3) filament current. It will be observed that life and emission vary enormously with small changes of filament voltage. As a well-known phrase has it: "A 5 per cent. increase or decrease of filament voltage halves or doubles the life."

The author then discusses details of total emission, etc., with reference to various characteristics given for the different types of valve.

It is pointed out that in telephony it is usual to light the valve filaments by direct

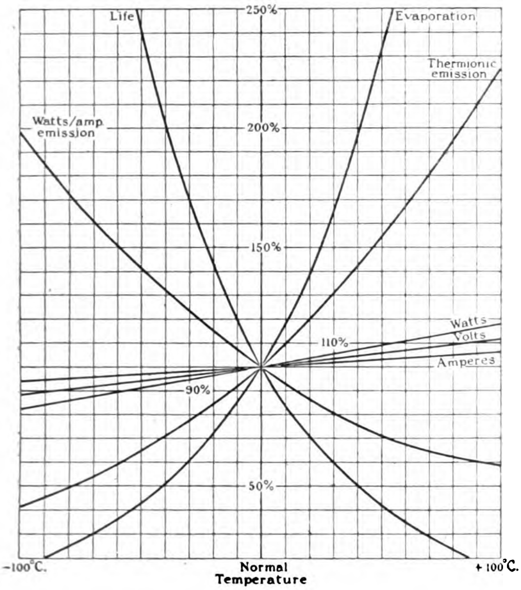

Fig. 26.

current in order to avoid hum. The emission current will return to the filament at its negative end, and if the filament polarity is never reversed this will cause greater evaporation and ultimately premature fracture near the negative end. The ideal method of reversing filament polarity is by heating it with alternating current. It is essential, however, that this current should not be synchronous with the alternating voltage applied to the anode. Various arrangements of phase to obtain this are discussed.

The life expectation of a valve—as for an electric lamp—is usually given as an average life.

If a batch of valves is taken of sufficient quantity to be representative, it will be found that filament burn-outs will begin at about one-half the average life, and that

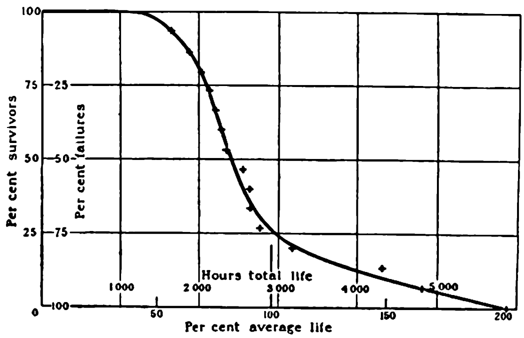

Fig. 36.

others will occur only after the valve has lived for twice its "life expectation."

Radiation cooled valves have now been in commercial use for sufficient time to enable adequate life data to be collected. These data are presented in the form of survivor curves. Various curves are given for such stations as Glace Bay, Munchenbuchsee (Berne), Ongar, Deutsch Altenburg (Austria), Barcelona, etc. Typical curves are given in Figs. 36 and 43.

In general survivor curves conform to three general types as shown in Fig. 45:—

The narrow.
The wide.
The linear.

The "narrow" type would appear to be normal for valves used under steady conditions as regards load, filament voltage, etc.,

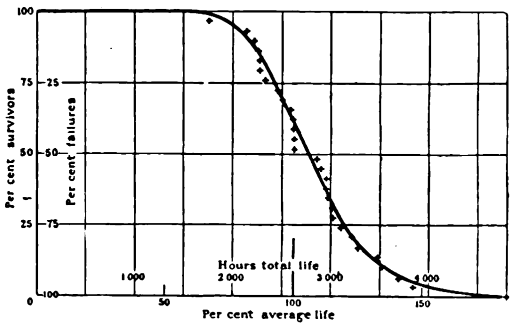

Fig. 43.

and at a loading well within the capacity of the valve.

The "linear" type results from variable conditions, overloading, excessive filament voltage, etc.

The "wide" type is probably a compound of several batches each giving narrow curves.

A table is also given showing the lives of cooled anode valves in use at Daventry, two valves having already given lives of upwards of 5,000 hours. The Carnarvon Station valve record for December, 1926, also shows several lives (at the end of the month reviewed) of nearly 4,000 hours.

Survivor curves can be used for two general purposes :—

To study the conditions under which valves are being used.

To study the behaviour of valves under given conditions.

The former assists in correcting wrong conditions of operation.

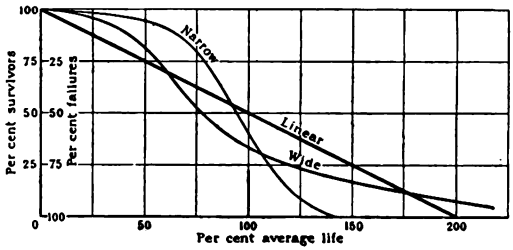

Fig. 45.

The latter assists in the calculations in valve design, and allows the effect of alterations and improvements in manufacturing processes to be watched.

It is too soon yet to give similar data regarding cooled-anode valves, but from the foregoing it will be seen that certain standards as regards average life have been established by radiation-cooled valves, and it is already evident that cooled-anode valves will not fall short of these standards.

DISCUSSION.

Dr. R. V. Hansford said the papers covered present-day practice in transmitting valves. The idea of a demountable valve was very useful, but he did not feel that it would become a serious rival until valves of 100-200kW were developed. Had these valves been used in parallel with common or with separate pumping ? With reference to the cooling of silica valves he thought that this necessity would make the ordinary cooled type of valve as useful. The silica type was not a serious rival for large powers. He made further reference to the discharge effect (referred to in his paper with Mr. Faulkner at the December meeting, abstracted in *E.W. & W.E.*, January, 1927) and described more recent tests made on the subject. In discussing life curves he showed a slide of performance of valves at Rugby. The need for the future was, he thought, for a fewer number of valves of greater power.

Mr. B. S. Gossling spoke of the apparent overlap in the three papers, but said that this was less than at first appeared because of the difference of functions mentioned. Development was limited by the conservative rating, and the comparison of valves for life and service was like the comparison between a motor bus and a high-speed racing car. In the cooled anode type the cathode was designed for long life.

Mr. J. R. Mullard asked if the Holweck valve had been used on short wavelengths. He did not agree that the silica valve had reached the limit of development. The cooling method (described in the second paper) was very important and helped in the process of manufacture to get a stable vacuum.

Mr. W. Gibson expressed particular interest in the second paper. He dealt especially with the survivor curves and said that the shape of the curve depended on the conditions of operation.

Mr. H. L. Kirke said that the cooled anode type had been successful in operation at Daventry. Discussing the peak/mean ratio of anode current, he pointed out that this ratio affected life and depended on the system of working. With reference to the second paper he asked for information of the power dissipated under oscillatory conditions.

Dr. Drane dealt with the desirability of keeping the valve as a discrete unit, free from cooling attachments. He suggested an air blast for this purpose, and discussed fragility, and asked for information as to the behaviour of silica valves under gunfire. He also dealt with X-radiation with silica valves and asked for information on the effects of this.

Mr. B. P. Dudding discussed survivor curves, and showed a slide illustrating the differences of survival according to the numbers of groups of valves working under different conditions of over-run, under-run, etc. He also asked for information as to the variation of vacuum during operation. Differences between glass and cooled anode valves suggested that this was important.

Mr. H. G. Hughes said that metal-glass valves cost two or three times as much as silica valves, while the latter were cheaper to repair. In tests of robustness silica valves had proved very satisfactory, and they had had no trouble due to gunfire. They had also had no trouble with X-radiation. With reference to the discharge, mentioned by Dr. Hansford, he attributed this to metallic deposits.

Dr. Bryan asked was there any difficulty in starting up the Holweck valve ? He had found such

difficulty in starting up another type on pumping. Was there any information as to the weight of the filament after burning ?

The authors replied briefly to the discussion.

Mr. C. F. Elwell agreed with the need for fewer and more powerful valves. He felt that there was no trouble in getting 100kW in a single Holweck valve. Two valves could be used in parallel on one pump with a *Y* feed. These valves had been used on wavelengths down to 37.5m., as mentioned in the paper. The filament was renewed when it had dropped by 10 per cent., and after a filament renewal, four or five minutes' preliminary pumping was necessary.

Mr. G. Shearing said he thought the limits of silica valves were above requirements and that in comparison they had proved the cheaper type. As regards the question of oscillating power, the anode dissipated that power when generating oscillations. Silica valves had been used down to 10 metres. He thought the demountable type might prove best for large powers.

Mr. W. J. Picken said that the survivor curves were desired to show that a law applied to failures according to the theory of possibilities. The curves were intended to help in determining the conditions of operation. His conservative estimate excluded Naval, Military and Air conditions, being limited to commercial conditions. 100kW valves were not now visionary but were near accomplishment. As regards X-ray transparency he had found that with a hard-glass valve at 15,000 volts D.C. X-ray effects were considerable.

On the motion of the Chairman (**Major B Binyon**) the authors were cordially thanked for their papers.

Abstracts and References.

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PROPAGATION OF WAVES.

Sur la Propagation des Ondes Electromagnétiques autour de la Terre (On the propagation of electromagnetic waves around the earth).—H. Gutton and J. Clément. (*Comptes Rendus*, 184, 14th March, 1927, pp. 676-678.)

In a preceding article (*C. R.*, 184, 1927, p. 441; these Abstracts *E.W & W.E.*, May, 1927, p. 312) experiments on the dielectric properties of ionised gases were described which led to the conclusion that the mutual actions between the electrified centres acted on these like quasi-electric forces and consequently determined the existence of an average oscillation period of the ions. As the mutual actions increase with the number of ions, this period must be the shorter the more ionised the gas, and in a periodic electromagnetic field resonance phenomena can be produced for frequencies that are the higher the greater the ionisation. In order to verify this latter point, the previous experiments were repeated employing shorter waves. It was found that for equal pressures the ionisation corresponding to resonance between the ionic oscillations and those of the field is much greater when the frequency of these latter is higher, also that the pressure beyond which no further apparent diminution of the dielectric constant is observed is higher. From the phenomena of resonance that exist in a gas and taking account of the fact that the period of resonance is the longer the weaker the ionisation, conclusions can be drawn as to the propagation of waves around the earth.

There is a mean ionic oscillation frequency corresponding to the ionisation of the lower part of the Heaviside layer. When short waves are propagated, the frequency of the electromagnetic field is higher than that of the ionic oscillations. The convection current produced by the movements of the ions is then in phase opposition with the displacement current and brings about an apparent diminution of the dielectric constant. As predicted by Eccles' theory, reflections and refractions send the waves back to the ground. For larger waves, the resonance period is reached. The convection current becomes in quadrature with the displacement current and no longer causes variation of the dielectric constant; it has the phase of a conduction current and effects marked absorption of the waves. Waves longer still have a frequency below the resonance frequency; the convection current is then in phase with the displacement current and produces an apparent augmentation of the dielectric constant. Refraction phenomena are no longer possible, but the waves are then sufficiently large for the conductivity of sea-water to assure long-distance propagation, in the conditions which are those of Austin's formula.

The phenomena happening on the two sides of the wavelength for which there is resonance in the ionised gas, when radio signals are transmitted, are thus very different. For frequencies close to resonance, distant transmission is not assured by the upper atmosphere which absorbs the waves. On the other hand, they are too short to be propagated along the ground without great attenuation. Thus is explained the fact often found, that waves in the neighbourhood of 200 metres are unserviceable for wireless telegraphy. Further, the reception of signals on these wavelengths is irregular and subject to marked fading. Indeed, in the vicinity of resonance, small changes of ionisation produce very large variations in the phase of the ionic oscillations and, consequently, considerable variation of the dielectric constant.

These experiments were made employing waves of 2 and 4 metres and large ionisations. The frequency of waves of 200 metres being much lower, the ionisation corresponding to resonance is weaker and can be reached in the upper atmosphere.

Expériences sur la Propagation des Ondes Radiotélégraphiques en Altitude (Experiments on the propagation of radio waves at an altitude).—P. Idrac and R. Bureau. (*Comptes Rendus*, 184, 14th March, 1927, pp. 691-692.)

In order to make a preliminary study of the propagation of short waves as a function of the altitude at which they are emitted, sounding balloons with transmitting equipment attached were sent up from Trappes Observatory. The signals, whose wavelength was about 42 metres, were heard at several meteorological stations as well as by different amateurs. Waves of the same length were also sent out on the ground, so that the conditions of propagation of the waves emitted in the air and at the earth's surface could be compared. The experiments showed that these can be entirely different: certain stations hearing the wave at the ground without that in the air, while others heard the wave in the air but not that at the ground. Several stations were able to follow the emission both ascending and descending with certain gaps for which the cause will only be able to be determined in subsequent experiments. In one ascent an altitude of between 13 and 14 kilometres was reached, which was probably the first time that waves were emitted in the stratosphere. The authors now intend to make a systematic investigation of the influence of altitude and that of the structure of the atmosphere on wave propagation.

A Comparison of the Variation of Intensity and Direction of Radio Signals.—H. Reich. (*Journ. Franklin Institute*, April, 1927, pp. 537-48.)

An account of experiments undertaken for the

purpose of recording and comparing simultaneous changes of direction and intensity in the broadcast band, particularly at the time of dawn and sunset; also simultaneous direction changes of signals from two or more stations.

The apparatus employed is described and the data obtained are shown graphically.

The conclusions drawn from the experiments are expressed as follows :—

1. Rapid and pronounced fading is usually accompanied by rapid direction changes of large amplitude throughout an evening, but there seems to be no correlation as to the exact time at which the changes occur for the two phenomena, or between the amplitudes of fluctuations over a short interval.

2. The two phenomena frequently begin and end almost simultaneously, but not always.

3. There is no correlation between direction changes in the signals from two different stations.

4. Although there almost always seems to be a pronounced deflection of fairly long duration shortly after sunset and shortly before sunrise, this is not always in the right direction to verify the theory of refraction at the border between day and night.

5. A display of the Northern Lights appears to result in an absence of directional minima on all stations.

THE SHORT-WAVE ECHO EFFECT.—(*E.W. & W.E.*, May, 1927, pp. 257-258.)

A brief article giving the new results on the propagation of short waves described by Herr Quäck in the December number of the *Zeitschrift für Hochfrequenztechnik* (these Abstracts, *E.W & W.E.*, March, 1927, p. 176). Assuming that the waves are propagated with the velocity of light *in vacuo*, the height at which they had travelled is worked out to 182 kilometres. In a note in the *Wireless World* of 23rd March, p. 356, a Berlin correspondent makes the height come to 350 kilometres, instead of 182 kilometres, on the same assumption.

In a letter to the *Wireless World* of 20th April, p. 505, and in the May number of *E.W & W.E.*, p. 259, Prof. Howe points out that this assumption giving the ionised layer a height of some hundred kilometres, is false. He shows that since the waves travel in an ionised medium they have a phase velocity higher and a group velocity lower than that of light, and that when this correction is made, the German observations are consistent with a height of about 90 kilometres, which agrees well with the value deduced from other experiments.

PHASE AND GROUP VELOCITIES IN AN IONISED MEDIUM.—G. W. O. HOWE. (*E.W & W.E.*, May, 1927, pp. 259-260.)

EAST OR WEST ?—(*Electrician*, 15th April, 1927, p. 403.)

The following paragraph appears among " Current Topics " :—

The number of times that the beam wireless system of signalling to Australia is reported upon in terms of East and West, is legion. One report even goes so far as to say that there are " two paths ; one goes over Europe and Asia, and the other West over the Atlantic, South America and the Pacific Ocean." While appreciating the fact that light and dark bands have to be considered, and that the " Heaviside layer " may give rise to some distortion of the actual route, we still see no reason why beam wireless waves should not be regarded as taking the shortest route, rather than following, more or less, the course steered by the Australian mail boat ! The fallacy of the argument of East and West is fully realised when the relative positions of England and Australia are studied on a globe, when it will be seen that for either the daylight or darkness bands, the most probable route for beam, or other radio waves, is one almost passing over the North Polar regions.

THE INTENSITY OF THE RADIATION FROM A SOURCE OF ELECTRIC WAVES WHEN THE ELECTRIC CONSTANTS OF THE MEDIUM IN THE NEIGHBOURHOOD OF THE SOURCE ARE DIFFERENT FROM THE ELECTRIC CONSTANTS AT A DISTANCE FROM IT.—H. Macdonald. (*Proc. Roy. Soc.*, 114, April, 1927, pp. 367-375.)

A mathematical discussion leading to the conclusion that in wireless telegraphy the amplitude of the oscillations is practically unaffected by differences in the electric constants of the atmosphere at a distance from the earth's surface.

THE SOLAR ECLIPSE AND ITS EFFECT ON RADIO.—H. de A. Donisthorpe. (*E.W. & W.E.*, May, 1927, pp. 293-300.)

A lecture delivered before the Radio Society of Great Britain on 23rd March, 1927.

HOLLAND—SHORT-WAVE TELEPHONY.—(*Electrical Review*, 25th March, 1927, p. 477.)

Telephone communication has been established between Holland and the Dutch East Indies constituting, it is claimed, a world's record for long-distance wireless telephony. The transmitter was constructed by Dr. B. van der Pol and Mr. Numans for experimental purposes, the antenna consisting of a single wire attached to a pole only 22 ft. from the ground. The wavelength was 30.92 metres.

ATMOSPHERIC ELECTRICITY.

THE MECHANISM OF A THUNDERSTORM.—G. Simpson. (*Proc. Roy. Soc.*, 114, April, 1927, pp. 376-401.)

The article is summarised as follows :—

A detailed description is given of the mechanism of a thunderstorm according to the theory in which the separation of electricity is brought about by the breaking of raindrops. The orders of magnitude of the meteorological and electrical quantities involved are investigated and shown to be in accordance with observations. The observations made by Schonland and Craib in South Africa of changes of electrical field-strength produced by lightning discharges are examined in the light of the theory and found to be in complete accord.

Atmospheric Potential at Varying Altitudes. —(*Electrician*, 1st April, 1927, p. 347.)

At the Aerodynamic Observatory at Trappes, sounding balloons have been employed to record the change of atmospheric potential with altitude. In general, the electric field becomes less with increasing altitude. The mean results were 10.4 V. per metre at 4,000 metres, 5.6 V. per metre at 6,000 metres, and 2.3 V. per metre at 8,000 metres. From the three balloons that entered the isothermal layer, the results at the lower limits reached a considerable value, amounting to from 30 to 40 V. per metre. The one balloon that reached an altitude of 20,000 metres showed that at heights above 16,000 metres there is a comparatively regular decrease, *e.g.*, 12 V. per metre at 16,000 metres, 5 V. per metre at 17,000 metres, and 1 to 2 V. per metre at 19,000 metres.

PROPERTIES OF CIRCUITS.

Influence on the Amplification of a Common Impedance in the Plate Circuits of Amplifiers.—J. Anderson. (*Proc. Inst. Radio Engineers*, 15, 3, March, 1927, pp. 195-212.)

It is pointed out that the common impedance in the plate circuits of two or more valves in an amplifier will affect the output, and under certain conditions cause distortion and oscillation. A theory is developed to explain this phenomenon. Several typical amplifier circuits are analysed with the theory and some experimental evidence is adduced in support of it. Methods of avoiding oscillation and distortion are suggested.

On the Variation of Frequency of a Generating Valve Circuit due to the Variation of Filament Current.—J. Obata. (*Proc. Physico-Mathematical Society of Japan*, January, 1927.)

It is well known that the frequency of the oscillation generated by a valve circuit does not absolutely correspond to the simple formula $n = \frac{1}{2\pi\sqrt{LC}}$, but is affected by various factors such as the resistance in the oscillatory circuit, voltages of the various batteries in use, temperature of the filament, coupling between portions of the circuit associated with the grid and anode, etc. The effects of these factors have been investigated by a number of authors (including Eccles and Vincent, *Proc. Roy. Soc.*, 96 and 97, 1920) with the result that of these various factors the filament current is found to play the principal part.

According to Vincent the frequency of oscillation in a generating circuit, maintained by a B valve with grid-coil coupling, has a minimum value for a certain filament current. This minimum would be useful, since in its neighbourhood change of filament current would have little effect on the frequency. Testing several valves, however, the author obtained no minimum in the frequency for any of them within the limit of the normal working value of the filament current. The experiments showed that the change in frequency decreases the looser the coupling. Of the various valves tested the change in frequency was found to be the smallest with the Radiotron 201A, employing loose coupling, but even with this arrangement it was by no means easy to obtain constant frequency for a long period of time.

The Theory of a Tuned R.F. Transformer.—G. Browning and F. Drake. (*Q.S.T.*, March, 1927, pp. 20-22.)

The mathematics given apply to any tuned radio-frequency transformer, whether for frequencies included in the broadcast band or some frequency chosen for the intermediate transformer; but the theory has only been checked with experimental curves over the broadcast band.

Discussion on the Output of Characteristics of Amplifier Tubes (Warner and Loughren).—(*Proc. Inst. Radio Engineers*, 15, 3, March, 1927, pp. 249-251.)

Coupling Condensers and Leaks.—A. Sowerby. (*Wireless World*, 20th April, 1927, pp. 481-483.)

An article showing how to calculate the correct values for any frequency.

The Application of a Generating Valve Circuit to the Measurement of Pulsatory Oscillations, Micro-tremors and Tiltings.—J. Obata. (*Proc. Physico-Mathematical Society of Japan*, January, 1927.)

Fragen der Antennenkopplung (Questions of antenna coupling).—E. Zepler. *Telefunken Zeitung*, 8, December, 1926, pp. 79-84.)

Considerations of the problems of intensity and selection in the cases of the tuned and the aperiodically coupled antenna, dealing in the latter case also with the question of the detuning of the tuned circuit by the antenna.

The current distribution in the antenna is taken throughout the discussion to be quasi-stationary as in practice is almost always the case.

TRANSMISSION.

Messungen im Strahlungsfelde einer in Grund-und Oberschwingungen erregten stabförmigen Antenne (Measurements in the radiation field of a linear antenna excited in its fundamental oscillation and harmonics).—L. Bergmann. (*Annalen der Physik*, 82, 4, 1927, pp. 504-540.)

The construction is described of a valve transmitter for generating undamped oscillations on a wavelength of 172 cm. that will excite a linear antenna in any odd or even number of harmonics. Measurements were made with a specially constructed receiver of the field radiated by the antenna excited in the fundamental oscillation and in different harmonics up to the sixth. When excited in the fundamental the whole radiation is sent out at right angles to the antenna in its equatorial plane, but when excited in the harmonics, radiation takes place in several directions: in fact, there are always as many directions of radiation as there are current antinodes along the antenna. Between the radiation diagrams obtained by

measurement and the curves calculated according to Abraham, there is very good agreement as concerns the different directions of radiation. With regard to the amplitude of the energy sent out, however, there was at first a divergence between calculation and measurement. The reason for this was when calculating hitherto it was always assumed that the current amplitude in the different oscillation antinodes along the antenna had the same value, whereas actually the amplitude of the current in the antinode where excitation is effected is considerably greater than in the neighbouring current antinodes: when this is taken into account in the calculation, theory and measurement agree also as concerns the amplitude. In various cases, the radiation of individual oscillation antinodes is prevented by the insertion of coils, producing a particular radiation diagram, which likewise agrees with calculation.

The results obtained are of value for short wave telegraphy in that, by exciting the transmitting antenna in harmonics, one is in a position to send out the largest part of the radiated energy not, as previously with long waves, perpendicular to the antenna, *i.e.*, parallel to the earth's surface, but making a more or less acute angle with the antenna and consequently sloping upwards, thereby sending the radiation from the outset into altitudes that are particularly favourable for the propagation of short waves.

There are 25 figures and 2 plates showing photographs of the apparatus.

Discussion on Radiation Resistance of a Vertical Antenna (Levin and Young).—S. Ballantine. (*Proc. Inst. Radio Engineers*, 15, 3, March, 1927, pp. 245-247.)

The Constancy of B.B.C. Transmissions.—W. Griffiths. (*Wireless World*, 20th April, 1927, pp. 497-500.)

Enumeration of factors governing the strength of received signals.

Crystal-Controlled Transmitter.—R. Bloxham. (*Wireless World*, 13th April, 1927, pp. 449-451.)

Practical details of a 50-watt installation working on 45 metres.

Some Possibilities and Limitations in Common Frequency Broadcasting.—De L. Martin, G. Gillett, I. Bemis. (*Proc. Inst. Radio Engineers*, 15, 3, March, 1927, pp. 213-223.)

Discussion of the nature of the problems involved in common frequency broadcasting where two cases call for consideration: two or more stations attempting to use the same frequency (*a*) with their own separate programmes, and (*b*) for sending out a common programme which is transmitted to them from a single source.

Die Rückwrikung bei fremdgestenesten Röhrensendern (Back action in externally modulated valve transmitters).—W. Kummerer. (*Telefunken Zeitung*, 8, December, 1926, pp. 20-25.)

It is explained how back action in externally modulated valve transmitters is brought about and the different methods for getting rid of it are discussed.

The Insulation of a Guyed Mast.—H. Miller. (*Proc. Inst. Radio Engineers*, 15, 3, March, 1927, pp. 225-243.)

Theoretical and experimental examination of the question as to the advisability of insulating the masts and guys employed to support the antennæ of high power transmitting stations. Under certain conditions this will increase the effective height and efficiency of the antenna giving a power saving that is worth more than the cost of the insulation and the increase in mechanical hazard, while under other conditions the increase in antenna efficiency may be insufficient to make the insulation worth while. No fixed rules can be given since each design of antenna and mast system presents a different problem. An attempt is made, however, to point out with the help of a characteristic example certain fundamental considerations and experimental methods that will assist in the economical insulation of guyed masts.

RECEPTION.

A New Receiver.—(*Electrician*, 1st April, 1927, p. 368.)

A series of receivers which are guaranteed for aural reception of any long wave C.W. station at the extreme limit of its range, has recently been developed by Marconi's Wireless Telegraph Co., Ltd. A comparatively small loop is used as an aerial, which helps to secure the desired degree of selectivity and eliminate atmospheric interference. The set itself is a seven-valve instrument comprising two tuned stages of high frequency amplification, followed by an "anode bend" rectifier, two low frequency filter systems with valve-coupled tuning circuits designed for a note frequency of 1,200 cycles, and a transformer coupled stage of note magnification. A "phasing unit" is incorporated in the set, which, consisting of a single valve and a simple inductively coupled circuit, gives greater selectivity should circumstances demand a higher standard than that given by the frame and receiver alone.

Electric Dust Precipitators and Radio Reception.—F. Muller. (*Siemens Zeitschrift*, January, 1927.)

Serious interference of radio reception has been observed in the previously occupied zones of Western Germany from the many electric dust precipitators installed in the surrounding mining districts. The trouble in all cases was found to be due to the synchronously driven rectifying spark gap, which changes the high voltage A.C. into approximately 50kV D.C. The secondary of the feeding transformer, together with the spark gaps and the capacity of the precipitators, forms an excellent oscillating circuit, emitting waves of 200 to 300 metres. Three ways of remedying the interference are suggested in this article: (1) Increasing the capacity by placing high-voltage condensers parallel to the precipitators. (2) Inserting ohmic resistance into the high-voltage connections at properly selected points. (3) Replacing the synchronous rectifiers by valve rectifiers.

SOURCES OF DISTORTION IN RESISTANCE AMPLIFIERS.—M. von Ardenne. (*Wireless World*, 30th March, 1927, pp. 395-399.)

Discussion of the influence on quality of anode resistance, grid leak, and coupling condenser valves.

LA RÉCEPTION PAR DOUBLE CHANGEMENT DE FRÉQUENCE (Reception by double change of frequency).—A. Cazes. (*Radio-Revue*, March, 1927, pp. 321-322.)

Description of a method of reception permitting the employment of the " bireflex " device patented by the author, discussed in *L'Onde Electrique* of August, 1926, p. 425.

QUELQUES OBSERVATIONS PRATIQUES SUR LA RÉCEPTION DES ONDES COURTES (Some practical observations on the reception of short waves).—*Radio-Revue*, April, 1927, p. 345.)

SUR LES CONTACTS RECTIFIANTS (On rectifyng contacts).—H. Pélabon. (*Comptes Rendus*, 184, 7th March, 1927, pp. 591-593.)

An instrument is described for studying the influence of the distance between the two conductors of a detector or the pressure they can exert on one another.

Employing a steel needle point and a galena crystal, two values for the detection were found corresponding to the interior and exterior regions for which the contact resistance assumes such different values. Measuring the rectified current when a small difference of alternating potential was set up between galena and point gave not only different current intensity for the two regions, but variations that were not comparable. The greatest intensity corresponds to the region offering the greatest resistance to continuous current. All the metals tested behave like steel when associated with galena, but the curves obtained differ sufficiently from one conductor to another for them to be considered as characteristic of the metal in question.

LOCATION OF RADIO INTERFERENCE.—B. Ellsworth. (*Electrical World*, 16th April, 1927, pp. 810-811.)

A list is given of 47 causes of radio interference due respectively to secondary lines, set noises, and power company's equipment. The procedure followed in tracing source of trouble is described and the equipment used.

DIRECTIONAL WIRELESS.

SUR LES PROCÉDÉS DE RÉPÉRAGE, D'ALIGNEMENT PAR LES ONDES HERTZIENNES ET SUR LES RADIOPHARES D'ALIGNEMENT (On methods of taking bearings and direction finding employing Hertzian waves and directive radio-beacons).—A. Blondel. (*Comptes Rendus*, 184, 7th March, 1927, pp. 561-565.)

It is known that, with the aid of antenna systems joined by one or two horizontal connections so as to make open or closed frames, we can effect the concentration of Hertzian waves in certain directions in space and, by means of interference, produce nodal planes, *i.e.*, planes in which no wave is propagated, in certain azimuths.

The author has already described three types of such frames, presenting different particulars :—

(*a*) A frame in which the two vertical antennæ are traversed by currents of opposite phase spaced at most a half wavelength apart : the nodal plane at some distance away is a plane perpendicular to the plane of the antennæ.

(*b*) A frame in which the two preceding antennæ are excited in the same phase, when the nodal plane coincides with the plane of the antennæ.

(*c*) A frame in which the difference of phase between the antennæ is equal to the phase lost by a wave travelling from one antenna to the other, when the nodal plane again passes through the antennæ but, differing from the two previous cases, the radiation distribution is unsymmetrical, the nodal plane existing only in a single direction.

Bellini has taken up the same subject in a more complete manner (*Jahrbüch*, 1909, p. 381). Frames of type (*a*) or (*b*) can be employed on short waves of 20 to 100 metres for indicating directions over sea or in the air corresponding to the nodal plane : exciting the frame by means of a suitable oscillation generating system producing musical waves being all that is necessary to establish a directive radio-beacon.

Details are given of a new system and also of the employment of very short waves of 5-10 metres with two directional curtain antennæ placed one above the other at an angle of 20°-30°, excited alternately, the plane bisecting the two curtains giving an accurate determination of the direction sought.

SUR LES RADIOPHARES TOURNANTS (On rotating radio-beacons). — A. Blondel. (*Comptes Rendus*, 184, 21st March, 1927, pp. 721-724.)

The double curtain arrangement for directive radio-beacons can also serve to construct rotating beacons giving more accurate readings than the devices tried hitherto (in particular the Marconi installation at Dover and Mesny's Greek-patterned rotating curtain). The two curtain antennæ are mounted on a trolley turning at constant speed and excited alternately at intervals sufficiently rapid to enable the navigator, knowing the speed of rotation, to read off his position. This he does by noting the moment when he hears the sounds equally, and referring it to the instant when he picks up a special signal, emitted automatically by an independent antenna when the plane bisecting the two rotating curtains passes through a cardinal landmark.

LA BOUSSOLE HERTZIENNE (The Hertzian compass). —H. Busignies. (*Radio-Revue*, March, 1927, pp. 309-319.)

Preliminary description of this compass, which appears to have advantages over the ordinary radiogoniometer principally for aeronautical use. It is understood that, from analogy with the ordinary compass which indicates the direction of the terrestrial magnetic field, the name Hertzian compass is intended to denote an instrument

indicating the direction of the electromagnetic field of Hertzian waves, or the direction, at right angles, of the transmitter of these waves, installed at the aerodrome. The apparatus, two forms of which are described, consists essentially of two similar receiving frames, perpendicular to one another, from which the currents induced by the transmitter are conveyed to two equal ordinary galvanometric frames pivoting round the same vertical axis, to which a pointer moving over a graduated scale is attached, indicating the deviation of the direction in which the craft is travelling from that of the transmitting station. The obvious advantage of the device is that no wireless operator is required, the pilot having merely to guide his craft so that the pointer keeps at zero on the dial in order to arrive at his destination. The compass is discussed here chiefly from the theoretical viewpoint, a commercial form of the instrument being under development, particulars of which the author hopes to give later.

DER NEUE TELEFUNKEN-PEILER E358N (New Telefunken bearings-finder E358N).—(*Telefunken Zeitung*, 8, December, 1926, pp. 41-44.)

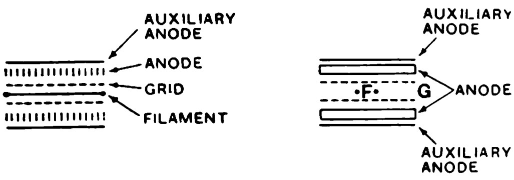
VALVES AND THERMIONICS.

ON THE APPLICATIONS OF VARIOUS ELECTRONIC PHENOMENA TO THERMIONIC VACUUM TUBES WITH PROPOSED NEW VACUUM TUBES.—K. Okaba. (*Journ. Inst. Elect. Eng. Japan*, No. 463, February, 1927, pp. 174-195.)

A paper with 25 figures showing applications to three and four electrode valves of various electron phenomena, especially electron reflection and secondary emission.

(*a*) A negative-resistance valve which utilises magnetic field only. This valve consists of filament, anode and auxiliary anode, with magnetic field applied. The effect of secondary electrons from the anode is negligible since a large proportion of the secondary electrons cannot be attracted by the auxiliary anode. If the voltage of the plate increases, the current through it decreases, on the other hand, if its voltage decreases, all of the thermoelectrons from the filament can be caught by the plate as there is no effect of secondary emission (including electron reflection). Thus this valve has negative resistance of very small value, which is a desirable characteristic for the generation of short waves.

(*b*) Excited four-electrode valve. This valve consists of filament, grid, anode and auxiliary anode as shown below:



The auxiliary anode is made of special material from which the secondary emission is very large. In this new valve the anode current consists of the secondary electrons from the auxiliary anode, which is a few times larger than that of the thermoelectrons from the filament, and its characteristics are quite similar to those of the triode. Experiment showed that the internal resistance of this valve is ½—⅓ that of the triode under the same conditions, giving the same amplification constant.

Lastly it is shown that oscillations of the Barkhausen and Kurz type may be maintained by the action of reflected and secondary electrons at the surface of the grid, assuming that the grid voltage is high enough and the plate voltage negative.

UNE NOUVELLE LAMPE PERMETTANT L'ALIMENTATION DIRECTE DE TOUS LES RÉCEPTEURS DE T.S.F. SUR LES RÉSEAUX À COURANT ALTERNATIF (LAMPE EURÉKA) (A new valve permitting the direct supply of all radio receivers from alternating current mains (Eureka valve)).—Lejeune and Givelet. (*Radio-Revue*, April, 1927, pp. 339-341.)

Lecture given to the Radio-Club de France, 24th February, describing the Eureka valve.

In this valve the filament heated by alternating current is distinct from the electron producing filament, but not as is usual under these circumstances a small distance away from it so that the emitting filament is heated by radiation; instead, the two filaments are in contact one being rolled round the other. Owing to the difference in resistance of the two filaments, only one-tenth of the alternating current passing through the emitting filament, and the supply tension being very low, the tension variations in this filament relatively to the grid are said to be altogether negligible.

The principal constants of this valve are given as:—

Heating tension: 1V. 4 to 1V. 6.
Heating current: about 1.5 amps.
Saturation current: 10 milliamps.
Amplification coefficient: 9 to 12.
Internal resistance (between filament and plate): 20,000 to 35,000 ohms.

A diagram of the circuit arrangement is shown.

THE ALIGNMENT METHOD IN LINEAR VALVE CHARACTERISTIC FIELDS. — W. Barclay. *E.W. & W.E.*, May, 1927, pp. 261-270.)

VACUUM-TUBE NOMENCLATURE.—E. Chaffee. (*Proc. Inst. Radio Engineers*, 15, 3, March, 1927, pp. 181-194.)

A scheme of symbols, for which no claim to completeness is made, is presented in the hope that it may serve as a step towards the early standardisation of a system of valve nomenclature.

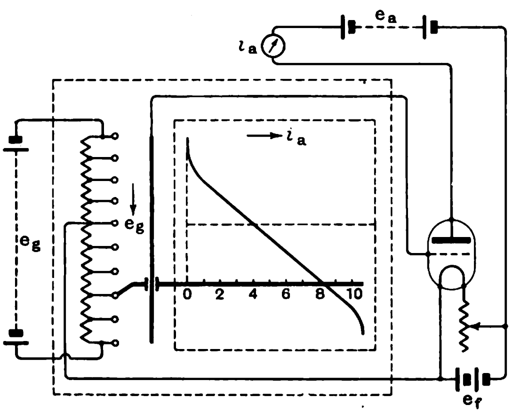
The proposed scheme is discussed by G. Metcalfe on pp. 253-254.

EINE EINFACHE RÖHREN-MESSPLATTE (Simple method of obtaining valve characteristics).—E. Römhild. (*Elektrotechnische Zeitschrift*, 3rd February, 1927, pp. 139-140.)

Usually the determination of the electrical characteristics of a valve requires complicated connections between batteries, resistances, instruments, etc., calling for the services of a skilled operator. In this article a semi-automatic valve

measuring instrument is described, of particular value for routine testing work by unskilled persons.

A diagram of the circuit-arrangement is shown below:



The slider of a potentiometer is mechanically connected to a movable straight edge, and readings from a directly indicating instrument are plotted along the straight edge while it is moved over a piece of co-ordinate paper. The whole apparatus is combined in a portable set.

La Bigrille à Reaction (The four-electrode valve with reaction).—E. Weil. (*Radio-Revue*, April, 1927, pp. 346-349.)

Account of experiments with the double-grid valve which is of interest at the moment owing to the employment of frequency changers in wireless telephony.

Modern Valve Manufacture.—J. Gracie. (*Wireless World*, 6th April, 1927, pp. 406-413.)

Electric Lamps and Valves.—(*Electrical Review*, 25th March, 1927, p. 494.)

Abstract of Mr. Paterson's lecture at the Royal Society of Arts on 16th February.

The nature is indicated of some of the problems encountered by manufacturers who seek a reduction of empiricism in process operations, efforts to solve them leading to fundamental questions which so far remain unanswered.

Choosing the Right Valve.—P. K. Turner. (*Wireless World*, 6th April, 1927, pp. 417-421.)

Characteristics required for the various stages in a multi-valve receiver.

How to Test your Valves.—W. James. (*Wireless World*, 6th April, 1927, pp. 425-428.)

Thermionic Properties of the Rare-Earth Elements.—E. Schumacher and J. Harris. (*Bulletin*, Reprint B-226, Bell Telephone Laboratories, January, 1927.)

Data are given showing that rare-earth metals of the cerium and yttrium groups are much more active thermionically than the commonly occurring metals, the electron emission from some being a million times as great as that from clean tungsten at the same temperature. The paper describes two methods of determining the thermionic activity of substances obtainable in powdered form.

GENERAL PHYSICAL ARTICLES.

Photo-Electric Emission as a Function of Composition in Sodium-Potassium Alloys.—H. Ives and G. Stilwell. (*Bell Telephone Laboratories Reprint*, B-238, March, 1927.)

The Characteristics of Gas-filled Photo-electric Cells.—N. Campbell. (*Philosophical Magazine*, 3, April, 1927, pp. 945-959.)

Beiträge zur Untersuchung des Nachhalles (Contributions to the study of the echo).—E. Meyer. ((*Elekt. Nachr.-Technik*, 4, 3, 1927, pp. 135-139.)

Description of a qualitative method of investigating echo phenomena, employing a Reiss microphone, an amplifier and oscillograph.

Experiments on Highly Penetrating Radiation from the Earth.—L. Bogoiavlensky and A. Lomakin. (*Nature*, 9th April, 1927, p. 525.)

Measurements of penetrating radiation from the earth carried out at Piatigorsk (in the Caucasus) by means of a portable electrometer covered with lead 1 cm. thick, show that the intensity fluctuates according to the observing station where the measurements are made. Differences of as much as 100 per cent. are observed between stations separated by a few metres only at places rich in radium. The intensity at the same station is found to be constant and independent of meteorological conditions. The radiations are found to be directed from below, their source lying apparently in radio-elements diffused in upper strata of the soil.

The full report of this work will be published in the *Bulletin* of the Institute of Practical Geophysics, Leningrad.

Measurements of the Amount of Ozone in the Earth's Atmosphere and its Relation to other Geophysical Conditions—Part II.—G. Dobson, D. Harrison and J. Lawrence. (*Proc. Royal Society*, 114, April, 1927, pp. 521-541.)

The article is summarised as follows :—

A method of measuring the amount of ozone in the upper atmosphere having been described in a previous paper, results of simultaneous measurements made at various places in N.W. Europe are given. As previously found, there is a marked connection between the amount of ozone and the meteorological upper-air conditions. The possible reasons for this connection are briefly discussed. Connections with terrestrial magnetism and possibly with sunspots are also indicated.

Water Vapour in the Atmosphere.—E. Gold. (*Nature*, 30th April, 1927, pp. 654-655.)

STATIONS: DESIGN AND OPERATION.

NEW WIRELESS STATION FOR CROYDON AERODROME. — (*Electrician*, 8th April, 1927, p. 396.)

The new station, which is to be erected for the Air Ministry by the Marconi Company, will consist of a group of four 3kW transmitters operated in conjunction with a wireless direction finding receiver. The transmitters will be capable of telephonic, C.W. and tonic train telegraphic transmission, the wavelength range being from 800 to 2,000 metres. Independent drive circuits will be incorporated to maintain constancy of frequency and wavelength. Energy for the transmitters is to be supplied by a common motor alternator group, the power from which may be switched on to any of the transmitters. The new D.F. apparatus will incorporate the latest filtering and amplifying devices. It is to be arranged so that, if required, two or more circuits can be operated on different wavelengths for the reception of telephony and telegraphy on the same aerials.

In order to keep the neighbourhood of the aerodrome as free as possible from obstruction, the wireless masts and transmitters will be erected two or three miles from the Air Port and operated by the "remote control" system.

DIE FLUGHAFEN-FUNKSTELLE HOF IN BAYERN (The air-port radio station Hof in Bavaria). —*Telefunken-Zeitung*, 8, December, 1926, p. 19.)

Brief description of the aerodrome radio station, 4 kilometres to the west of Hof in Bavaria, recently constructed by the Telefunken firm for the Imperial Ministry of Communications. The site is 140 metres above Hof and 550 metres above sea level. The two lattice masts, which are 45 metres high and 70 metres apart, support the 3-wire T-antenna 64 metres long and 4 metres broad having a natural wave of about 550 metres and capacity 1,100 cm. The earth system has an area of 4,000 sq. cm. and is buried in the ground 30 cm. deep. The transmitter is a self-excited intermediate circuit valve transmitter of about 1.5kW resultant antenna output for distances of from 800 to 1,800 metres and is arranged for both unmodulated and modulated (note transmitter) telegraphy and for telephony.

IRISH FREE STATE—CORK STATION.—(*Electrical Review*, 1st April, 1927, p. 519.)

The new broadcasting station at Cork of the Department of Posts and Telegraphs, constructed by Standard Telephones & Cables, Ltd., London, has almost completed its tests. It is located at Sunday's Well, and occupies the site of the old prison. Two 120-ft. masts support the aerial, which consists of four wires each 156 ft. long; an earth mat, composed of a network of copper wires, has been buried in the ground covering an area of approximately 20,000 sq. ft. The station is rated at 1.5kW, and with 100 per cent. modulation a "peak" power of 4kW can be handled without distortion, assisted by the use of a condenser microphone. The frequency of the carrier wave is maintained constant within 0.01 per cent. The power required to operate the complete station is about 9kW, obtained from the local supply mains and used to drive motor generators. It is hoped that this station will cover the south and west of the Free State. The wavelength is 400 metres.

BROADCASTING DEVELOPMENTS IN THE IRISH FREE STATE.—(*Electrician*, 29th April, 1927, p 480.)

Particulars are given of the equipment of this new broadcasting station which was opened formally on 25th April.

SHORT-WAVE BEAM TRANSMISSION.—(*Electrician*, 8th April, 1927, pp. 378-379.)

Continuation of the description of the Grimsby Station begun in the *Electrician* of 25th March. The present article considers the masts and aerial equipment, feeder system and special earthing arrangements.

On p. 396 it is stated that a second beam station is now being completed in Australia to give a direct service between that country and Montreal. The Montreal service will also be available, if required, as an additional channel of communication with London, linking up with the Anglo-Canadian Beam. Wireless feeder stations have been erected at all the Australian capital cities to work in conjunction with the beam service, and additional accepting and delivery offices in the State capitals will be opened as occasion demands.

AUSTRALIAN BEAM SERVICES.—(*Wireless World*, 30th March, 1927, pp. 378-379.)

Description of the Grimsby and Skegness Stations.

AUSTRALIA—NEW RECEIVING STATION.—(*Electrical Review*, 1st April, 1927, p. 519.)

The La Perouse radio receiving station was opened recently by Amalgamated Wireless (Australasia), Ltd. It is capable of receiving messages from Tilbury Docks, London, as well as from the docks in Vancouver and San Francisco, and has also kept in communication with ships fitted with short-wave sets between these terminal ports. It will be the official receiving centre for Sydney, and will be in direct communication with all the "beam" feeder stations in Australia, and automatically relay the messages received direct to the head office of the Company. The same procedure will be followed regarding messages received from the Federal Government stations in New Guinea and the Pacific Islands, which are controlled by Amalgamated Wireless, Ltd. The aerial system at La Perouse consists of four 72-ft. tubular steel masts in the form of a square, with one 99-ft. mast in the centre. All transmitting will be done from the Pennant Hills, about 30 miles distant.

DER RHEINLANDSENDER (The Rhineland transmitter).—W. Meyer. (*Telefunken Zeitung*, 8, December, 1926, pp. 8-19.)

Detailed description of the Langenberg broadcasting station with 25 diagrams and illustrations.

SUBSIDIARY APPARATUS.

GRUNDLEGENDES ZU UNTERSUCHUNGEN AN MIKROPHONEN (Principles of microphone investigation).—G. Schubert.

The difficulties of studying microphones are considered in detail and methods of making objective tests suggested.

LOUD-SPEAKER DESIGN.—N. McLachlan. (*Wireless World*, 30th March and 13th April, 1927.)

BATTERY ELIMINATORS.—(*E.W. & W.E.*, May, 1927, pp. 271-278; *Wireless World*, 27th April, pp. 535-538; *Electrician*, 29th April, p. 466.)

Abstracts of a paper read by Messrs. P. Coursey and H. Andrewes before the Wireless Section, I.E.E., on 6th April, 1927.

A NEW FREQUENCY TRANSFORMER OR FREQUENCY EXCHANGER.—I. Koga. (*Journ. Inst. Elect. Eng. Japan*, No. 463, February, 1927, pp. 146-156.)

Description of a triode arrangement that will not only multiply the frequency of an alternating current, but will also obtain such frequencies as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{3}{2}$, $\frac{4}{3}$, etc., of the given frequency. The behaviour of the apparatus is shown to be due to the non-linear characteristics of the triode.

MISCELLANEOUS.

SUCCESSFUL TELEVISION DEMONSTRATION OVER 200 MILES. — (*Electrician*, 15th April, 1927, p. 420.)

Television was successfuly demonstrated on 7th April by the American Telephone and Telegraph Co., Ltd., to a group of newspaper representatives at its Bell Laboratories, New York. They saw Mr. Hoover, Secretary of Commerce, leaning over the telephone in Washington, 200 miles away, and watched his image on a screen as he spoke.

In this connection it is interesting to note that Mr. Baird claims to have established television between London and New York, proposing to give a public demonstration shortly. The tests are expected to show the commercial practicability of television, and if they are successful, televisors will be placed on the market at a cost of £30.

TELEVISION BECOMES AN ACTUALITY.—(*Electrical World*, 16th April, 1927, pp. 824-825.)

Account of the demonstration on 7th April given by the American Telephone and Telegraph Company, when speakers at Washington were seen in action on a screen in New York. The transmission was effected by wire, but the fact that radio will serve equally well was proved by the audience being shown, at the same time as hearing, a performance from the Whippany studio transmitted by wireless. In the method developed a minute spot of very bright light is projected upon the object to be transmitted and moved to and fro so that the details of the entire surface are successively illuminated. This light is reflected back upon the photo-electric cell which generates a current in direct proportion to the amount of light falling upon it. This current, amplified many million million times, is that which is transmitted. Previous experimenters had tried to secure complete illumination of the object by pouring a tremendous flood of light upon it. The use of the new scanning method makes it possible to employ a very small quantity of light instead of an amount that would be unbearable to performers.

COMMERCIAL PICTURE TRANSMISSION.—A. Dinsdale. (*Wireless World*, 27th April, 1927, pp. 510-516.)

A technical description of the methods and apparatus used in America.

DIE FORTSCHRITTE DER BILDTELEGRAPHIE TELEFUNKEN-KAROLUS-SIEMENS (Progress of picture telegraphy on the Telefunken Karolus Siemens method).—F. Schröter. (*Telefunken Zeitung*, 8, December, 1926, pp. 5-8.)

Illustrated description of this method which was successfully used last autumn to send pictures between Nauen and Rio, a distance of about 10,000 kilometres, on a wave of 25 metres.

DIE UMWANDLUNG EINES BILDES IN ELEKTRISCHE TELEGRAPHIERZEICHEN (Converting a picture into electrical signs for telegraphing). — O. Schriever. (*Telefunken Zeitung*, 8, December, 1926, pp. 35-40.)

FRANCE—NEW REGULATIONS.—(*Electrical Review*, 1st April, 1927, p. 519.)

BRITISH EXPORT FIGURES OF RADIO APPARATUS, INCLUDING VALVES.—(*Electrician*, 1st April, 1927, p. 368.)

From recent export figures Japan appears to be the biggest importer of radio apparatus and instruments of British manufacture, in that during the last recorded month (January) goods valued at £14,096, together with valves valued at £588, were shipped to that country. Russia imported goods to the value of £11,032, and valves to the value of £91. Australia absorbed apparatus to the value of £10,618 and valves to the value of £2,362. Sweden's import of apparatus and instruments was £5,270 and of valves £1,122. New Zealand imported apparatus with £3,820 and valves £640. Canada's figures were £1,228 and £922. France took apparatus and instruments valued at £3,543 and valves £1,385. Germany's totals were £1,519 and £2. The Irish Free State bought apparatus of British make valued at £2,488 and valves at £256. The Netherlands bought almost £5,000 worth of apparatus, as well as valves to the value of £300.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

EĤA EFEKTO DE MALLONGAJ ONDOJ.

Redakcia artikolo pritraktanta la konatan fenomenon de "eĥa" efekto, kaŭze de ondoj, kiuj transiras longan distancon laŭ malsamaj vojoj. Oscilogramoj estas donitaj por ilustri la efekton, kun frapanta ekzemplo, kie la ĉefa signalo estas vojaĝinta nur kelkajn kilometrojn kaj la eĥa signalo estas ĉirkaŭinta la terglobon.

FAZAJ KAJ GRUPAJ RAPIDECOJ EN IONIZITA MEDIO. —Prof. G. W. O. Howe.

La artikolo diskutas eksperimentojn faritajn en Berlin por determini la tempon uzitan de mallongonda signalo ĉirkaŭi la terglobon, per kio oni faris deduktojn pri la longeco de la vojo, kaj alteco de la vojo super la tero. Oni atentigas, ke du aferoj devas esti konataj—la tempa intervalo kaj la rapideco de la ondo. La prelego tiam diskutas la rapidecon de la ondgrupo kiel tuto, kaj la "faza rapideco," kaŭze de la moviĝo de individua ondo en la grupo. Oni montras, ke ĉi tiuj estas respektive malpli kaj pli grandaj, ol la rapideco de lumo, kaj estas funkcioj de la elektrona denseco en la medio. La aŭtoro poste traktas pri korektoj aplikataj al la Germana takso pri alteco, laŭ diversaj valoroj de grupa rapideco kaj elektrona denseco.

LA SUNA EKLIPSO KAJ ĜIA EFEKTO JE RADIO.

Raporto pri lekcio antaŭ la Radio-Societo de Granda Britujo, de Kapitano H. de A. Donisthorpe, je 23a Marto 1927a.

La lekcio traktis pri la efektoj de la suna eklipso je 24a Januaro, 1925a. Li priskribis radio-observadojn en Nova Jorko, kaj diskutis velkajn efektojn, kun ilustrajoj de la observadoj laŭ la pozicioj de la stacioj rilate al la tuteklipsa regiono.

Sugestoj por la radio-observadoj je la okazo de la okazonta eklipso je 29a Junio estas fine donitaj, kune kun raporto pri la diskutado, kiu sekvis la paroladon.

RICEVADO.

DESEGNO KAJ KONSTRUO DE SUPER-HETERODINA RICEVILO.—P. K. Turner.

Kvankam la prelego pretendas esti "Priskribo," la teorio kaj principoj de supersona funkciado estas ankaŭ klare pritraktitaj.

La aŭtoro unue konsideras la efekton de la loka oscilatoro kaj la diversaj frekvencoj, kiuj ekzistas ĉe la enmeto kaj elmeto de la unua detektoro. Li poste traktas pri la Intera frekvenca amplifikatoro, diskutante la tipon de resonanco bezonita; de tio al la dua detektoro kaj malaltfrekvenca amplifikatoro. Li poste revuas eblajn ŝparojn per kombino de valvaj funkcioj, kiel ĉe refleksaj cirkvitoj, kaj priskribis eksperimentojn je konstruado de supersonaj riceviloj. La unua ricevilo havis 4 valvojn, kombinita detektoro-oscilatoro (laŭ la dua harmonika principo), 3 valvoj je inter frekvenco, dua detektoro-kristalo, kaj du el la I.F. valvoj ankaŭ funkciantaj kiel malaltfrekvencaj. La malfacilaĵoj renkontitaj estas priskribitaj, ĉefe harmonikoj en la oscilatoro, kaj ĝenoj okazantaj pro refleksado de la elmeta valvo. Dua ricevilo estas poste priskribita, al kiu estis aldonita elmeta altpotenca valvo. La "Tropodina" cirkvito por la oscilatora-detektora pozicio estas diskutita, kaj modifaĵoj por plibonigi la ekvilibron estas sugestitaj. La artikolo estas daŭrigota.

BATERIAJ FORIGILOJ, aŭ Instrumentoj por la Funkciigo de Radio-Ricevilaj Cirkvitoj per Energio ricevita el Elektraj Ĉef-tuboj.

Resumo de prelego legita de S-roj. P. R. Coursey, B.Sc., M.I.E.E., kaj H. Andrewes, B.Sc., antaŭ la Senfadena Sekcio, Instituto de Elektraj Inĝenieroj, Londono, je 6a Aprilo 1927a.

La prelego diskutas la provizon de Alta-Tensiaj, Malalta-Tensiaj, kaj Krad-Potencialaj voltkvantoj pere de la publikaj elektraj ĉeftuboj. La aŭtoroj sugestas la nomon "Radio-Proviziloj," anstataŭ la pli kutima termino "Bateriaj Forigiloj."

La prelego traktas pri ĝeneralaj principoj, poste pri Alta-Tensia provizo, inkluzive alĝustigo de elmeta voltkvanto, funkciigo kaj desegnado de A. T. filtrilo, permesebla ondeta voltkvanto, takso de A. T. proviziloj kaj mezurado de elmetaj karakterizoj. Oni donas kurvojn montrantajn la efekton de l'elektraj konstantoj de la filtrila aranĝo, kaj tabelo kaj kurvoj montras mezuritajn elmetajn koeficientojn de diversaj komercaj A.T. Proviziloj. La prelego poste pritraktas aranĝojn por krada potencialo, malalta-tensia provizo, kun filtrilaj aranĝoj, rektifikatoroj por A.T. kaj por M.A.T. provizo, k.t.p. Fina sekcio traktas pri antaŭzorgoj necesaj je la uzado de tiaj aranĝoj.

Mallonga raporto aperas ankaŭ pri demonstracio donita dum la lekcio kaj pri la diskutado, kiu sekvis la legadon de la prelego.

VALVOJ KAJ TERMIONIKO.

La Alliniiga Metodo ĉe Liniaj Karakterizaj Kampoj.—W. A. Barclay.

Plua kontribuaĵo de ĉi tiu aŭtoro pri l'uzado de la alliniiga principo ĉe la kalkulado de senfadenaj problemoj. Je nuna okazo la metodo estas aplikita al la linia regiono de valvaj karakterizoj.

Oni montras, ke la anoda kurento estas esprimita de

$$i_a = \frac{v_a + \mu_o v_g - v_o}{R_o}$$

kaj ke la aktuala voltkvanta pligrandiga μ obtenita kiam rezistanco R estas enmetita en la anodan cirkviton estas esprimita de $\mu = \mu_o \frac{R}{R+R_o}$

Alliniiga grafikaĵo por la determino de unuj el ĉi tiuj kvantoj estas poste montrita. La metodo de konstruado de la grafikaĵo laŭ eksperimentaj informoj estas plene klarigita, la diversaj paŝoj estante ilustritaj diagrame, kaj pruvitaj kiam necese. La praktika funkciado de la diagramo estas fine priskribita, kun etato pri ĝiaj multaj utilecoj.

DIVERSAĴOJ.

Resumoj kaj Aludoj.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

Matematiko por Senfadenaj Amatoroj.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna artikolo komencas Parton II de la serio, kaj traktas pri Geometrio kaj Trigonometrio, la Rekta Linio, Anguloj, la Triangulo, Paraleloj, Egaleco de Trianguloj, Geometria Simileco, la Trigonometriaj Proporcioj, k.t.p.

Libra Recenzo.

Recenzo de L. Hartshorn pri la libro " Elektraj Kondensatoroj," de Philip R. Coursey.

Book Review.

Wireless Loud-Speakers. A Practical Manual Describing the Principles of Operation, Performance and Design. By N. W. McLachlan, D.Sc., M.I.E.E., F.Inst P. Pp. 139, with 86 illustrations and diagrams. Published by Iliffe & Sons, Ltd., London. Price, 2s. 6d. net, by post 2s. 8d.

Perfection in component parts of receiving apparatus is the aim of all those engaged in the design of wireless apparatus for broadcast purposes and it is probable that no individual component has of late attracted more thought and attention than the loud-speaker. Designers will, therefore, welcome a practical manual by Dr. N. W. McLachlan, describing the principles of operation, performance and design of loud-speakers, with a special reference to the type which has come to be known as the " coil drive."

The preliminary chapters of the book are devoted to a discussion of the general acoustic principles involved in the design of sound reproducing apparatus, showing how the quality of sound is determined largely by the number and nature of the overtones, with clear, practical observations on the sensitivity of the human ear at different frequencies, the effect of resonance on complex sounds, and the influence of loudness on the quality of reproduction.

The author next deals with the problems involved in the design and construction of the horn type of loud-speaker, the length of horn theoretically required for proper reproduction, and descriptions of various standard types already on the market. A short chapter on the principles of hornless or large-diaphragm loud-speakers leads us to a more detailed exposition of the action of the diaphragm, its shape and size, and the object of baffles.

Probably the most interesting section of the book is that which is devoted to a description of the author's design of a hornless loud-speaker of the coil drive type. The author has appreciated the fact that the design of the amplifier to be used with the loud-speaker is of equal importance with the design of the speaker itself, and further chapters are devoted towards the end of the book to the design of amplifiers where volume can be obtained without a sacrifice in quality.

The book is the only work of the kind devoted to the subject and probably there is no one better acquainted with the subject than the author. He has the further advantage of being free to discuss and give details of the experimental work he has carried out, whereas others who may be working on the same problem both here and abroad, are mostly prevented from disclosing their work on account of their associations with commercial companies.

The book is well illustrated both with photographs and detailed drawings.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

The Audio-Transformer Problem.

To the Editor, E.W. & W.E.

SIR,—I have followed with interest the correspondence on this subject, but cannot help feeling that the very divergent opinions held by the opposing schools of thought are due to the fact that each side is neglecting certain factors of the problem. May I therefore state it in the simplest form?

Fig. 1 shows the circuit, e_1 being generated in the anode circuit and R_a the anode slope resistance. The turns ratio is s, and the leakage is taken as zero, so that the mutual reactance is sX_1. The transformer ohmic resistance and core losses are neglected.

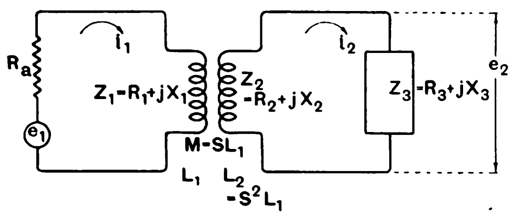


Fig. 1.

We then have, for any definite frequency,

$$i_2 = \frac{jsX_1}{js^2X_1+Z_3} i_1 \quad \dots \quad \dots \quad (1)$$

As will be shown later, the most critical conditions are at low frequencies, and we will therefore consider such frequencies. This means that the capacity load on the secondary will be of very high impedance, as will also be the resistive load. The apparent input impedance is then $Z' = R' + jX'$, where

$$\left.\begin{aligned} R' &= R_1 + \frac{s^2X_1^2}{Z_3^2} . R_3 \\ X' &= X_1 - \frac{s^2X_1^2}{Z_3^2} . X_3 \end{aligned}\right\} \quad \dots \quad \dots \quad (2)$$

Equations (1) and (2) are well-known transformer expressions, correct beyond any doubt.

Thus, under these conditions,

$$Z' \doteqdot Z_1 \doteqdot R_1 + jX_1 \quad \dots \quad \dots \quad (3)$$

Then

$$i_1 = \frac{e_1}{R_a + jX_1} \quad \dots \quad \dots \quad (4)$$

(neglecting R_1). From (1) and (4),

$$i_2 = \frac{sX_1}{Z_3} \frac{e_1}{R_a + jX_1} \quad \dots \quad \dots \quad (5)$$

(neglecting s^2X_1 in comparison with Z_3)

Hence

$$e_2 = Z_3 i_3 = \frac{sX_1}{R_a + jX_1} e_1 \quad \dots \quad (6)$$

Putting $e_2/e_1 = \eta$, we have

$$\eta^2 = s^2 \frac{X_1^2}{R_a^2 + X_1^2} \quad \dots \quad \dots \quad (7)$$

This is (except for the factor s^2) the well-known form of expression for choke coupling. It seems to indicate that the "Duff" school—high primary impedance—is correct. But the tale is not yet told.

Equation (7) includes as factors both s and X_1, and these are not independent. For η to be large, we want *both* these factors to be large. But both practical considerations of space and cost, and theoretical considerations of capacity and leakage effects, place a limit on the amount of secondary winding which can be accommodated. In fact, we can put $s^2X_1 = A$ where A is a constant determined by these considerations.

We then have

$$X_1 = \frac{A}{s^2} \quad \dots \quad \dots \quad \dots \quad (8)$$

and (7) becomes

$$\eta^2 = \frac{A^2/s^2}{R_1^2 + A^2/s^4} = \frac{A^2s^2}{s^4R_a^2 + A^2}$$

or

$$\frac{1}{\eta^2} = \frac{1}{s^2} + \frac{R_a^2}{A^2} s^2 \quad \dots \quad \dots \quad (9)$$

There is, then, an optimum value for s, and it is easily found that $1/\eta^2$ is a minimum for

$$s^2 = \frac{A}{R_a} \quad \dots \quad \dots \quad \dots \quad (10)$$

from which and (8) we have

$$X_1 = \frac{A}{s^2} = R_a \quad \dots \quad \dots \quad (11)$$

So that, when we remember that the secondary cannot be made indefinitely large, the "Fowler-Clark" school appear to be in the right!

But still we have not finished with the subject. The above analysis is for a fixed frequency, and

since X_1 varies with frequency while R_1 does not, we must obviously find what happens for other frequencies. Suppose that Equation (11) holds for the frequency $\omega_0/2\pi$, so that

$$L_1 = \frac{X_1}{\omega_0} = \frac{R_a}{\omega_0} \quad \ldots \quad \ldots (12)$$

then, for any frequency $\omega/2\pi$

$$X_1 = \omega L_1 = \frac{\omega}{\omega_0} R_a \quad \ldots \quad \ldots (13)$$

Hence, from (7),

$$\eta^2 = s^2 \frac{X_1^2}{R_a^2 + X_1^2} = s^2 \frac{\frac{\omega^2}{\omega_0^2} R_a^2}{R_a^2 + \frac{\omega^2}{\omega_0^2} R_a^2} = s^2 \frac{\omega^2}{\omega_0^2 + \omega^2} \quad (14)$$

and the latter part of this expression shows that as ω increases beyond ω_0, η rapidly tends towards s, while for $\omega < \omega_0$, it falls off rapidly. Hence ω_0 must be the lowest frequency to be dealt with. Since, as a rule, we wish to deal with very low frequencies in musical reception, we usually make ω_0 as low as we can, which means that L_1 $(= R_a/\omega_0)$ will be as large as we can make it.

If, when we have made L_1 and L_2 as large as we can, ω_0 is still higher than we should like, it can be reduced by decreasing R_a since (from (12))

$$\omega_0 = \frac{R_a}{L_1}$$

According to the above analysis, η would be constant and equal to s for values of ω well above ω_0. But here we meet with the factors that we have neglected. Self and mutual capacities make a load on the secondary, and leakage becomes important: equation (3) no longer holds, and the whole problem becomes much more complicated.

Summing up :—

1. Mr. Clark is correct in that *if* X_1 *is the only variable*, η is a maximum for $X_1 = R_a$.

2. But since X_1 should $= R_a$ for the lowest frequency to be received, then for musical work L_1 will probably be limited simply by the wire that can be got on.

3. To extend the range of low frequencies, L_1/R_a should be increased, if necessary, by reducing R_a.

4. At high frequencies, the effects are much more complicated, and both self capacity and leakage must be allowed for.

P. K. TURNER.

New Eltham.

A New Development in Resistance Amplification.

To the Editor, E.W. & W.E.

SIR,—In reply to the letter from Mr. Scroggie in your issue for May :—

The best condition for efficiency of anode bend rectification with a valve coupled to the next valve by means of a resistance in the anode circuit, is that the effective anode circuit impedance shall be small for the radio-frequency currents in the anode circuit and as high as possible compared with the internal resistance of the valve for the low frequency components. The use of very high anode resistances of the order suggested in my paper fulfils both these conditions as far as the broadcast range of wavelengths is concerned. In connection with the first condition it should be remembered that the effective internal impedance of the valve under these conditions of operation is considerably higher than that corresponding to the straight line region of the valve characteristics.

If grid rectification is employed the second condition still applies, but the first need not be fulfilled except in so far as it is desirable to prevent radio-frequency currents passing into the low-frequency stages of the amplifier. This point is alluded to again below.

In connection with anode-bend rectification it is important to realise that the effective rectilinearity of the anode current characteristic is maintained only with respect to grid voltage changes of low frequency; and the shape of the working characteristic as far as radio-frequency grid potential is concerned will show pronounced curvature owing to the fact that the external anode circuit impedance is not high compared with the internal impedance of the valve. This fact is difficult to realise in the absence of a detailed analysis which would be out of place in a letter, but it explains why quite satisfactory high-frequency rectification is obtained with a grid voltage that corresponds apparently to a straight region of the D.C. working characteristic; while the low frequency rectification will be negligible under the same conditions. These deductions are confirmed by practice.

Finally, I would like to take this opportunity of emphasising a very important matter relating to multi-stage amplification by the high resistance method.

A recent paper by Mr. L. Hartshorn, "The Input Impedances of Thermionic Valves at Low Frequencies" (*Proc. Phys. Soc.*, Vol. 39, Part 2, pp. 108-122) makes it clear that the effective grid-filament capacity of a valve may reach quite large values—100$\mu\mu$F or more—when the anode circuit contains a high resistance. Further, the higher the voltage factor of the valve, the larger this input capacity is likely to be. Such capacities will have a material shunting effect at high audio frequencies and undoubtedly constitute the real limiting factor as far as uniformity of frequency response is concerned. The analysis of the coupling conditions given in my paper is quite valid under the conditions stated, *i.e.*, that the shunt effect of grid-filament capacity shall be unimportant. It appears, however, that with high voltage factor valves of relatively high internal impedance this shunt effect may not be unimportant at the higher audio frequencies, and may result in a falling off of amplication at the high frequency end. This fact is recognised by Von Ardenne, who originated this method, and is confirmed by the character of some of the curves published by him in his descriptive article in a recent number of the *Wireless World*, though the full explanation of the effect is more explicitly given in the paper by Mr. Hartshorn referred to above.

The satisfactory quality of the reproduction given by amplifiers using high anode resistances and high voltage factor valves seems to indicate that the effect is not so detrimental as one might imagine at first sight. Nevertheless it calls for a rather more careful consideration of the effect of the input capacity of the succeeding valve than is given in my paper (which, by the way, was written more than a year before Mr. Hartshorn's paper was published). I have called Mr. Hartshorn's attention to the matter and there is a possibility that he will at some future date complete the analysis given in my paper in this respect.

As far as Mr. Scroggie's last query is concerned—it should now be clear that radio-frequency amplification through a multi-stage high resistance amplifier is not likely to be appreciable, at least as far as shorter wavelengths (3,000 metres or less) are concerned. Any residual voltage transference could possibly be minimised by connecting a radio-frequency choke between the anode and the anode resistance, the coupling capacity being connected to the common point of the choke and the resistance, but this arrangement I have not had any occasion to try.

F. M. COLEBROOK.

Radio Research During the Eclipse.

A NUMBER of important tests will be conducted by the Department of Scientific and Industrial Research under the auspices of the Radio Research Board during the solar eclipse on 29th June, the main details of which were arranged at a conference at which representatives from most of the wireless interests were present.

The main observations will be carried out under the supervision of Prof. E. V. Appleton, F.R.S., with the aid of photographic recording apparatus installed in the experimental station of the Department at Peterborough.

The B.B.C. has promised to co-operate as regards transmissions to be sent out, on a wavelength within the ordinary broadcasting band, either from Daventry or Birmingham, while simultaneously observations will be made at Liverpool on their Newcastle station.

It is expected that the eclipse will afford a valuable opportunity for studying the variation in directional effects which take place at sunrise and sunset and will serve to enable those conducting research in connection with these phenomena to check and verify the data already obtained. D.F. observations will be taken from the B.B.C. station at Manchester, at Slough, and at Bristol University. It is also hoped that this work will be supplemented by observations at the experimental stations of the G.P.O.

The variation in signal strength of long-wave stations will also be the subject of special tests. Transmissions from a Continental station will be measured at Slough and with special apparatus installed at Aberdeen University, while checking observations will be made at Rugby. Similar long-wave tests will be made independently by Prof. Marchant, using his own method for the measurement of signal strength with apparatus, in the Liverpool University. The observed station in this case will probably be a high-power Scandinavian station in the line of totality.

The intensity measurements of the strength of atmospherics is another contemplated series of tests. Observations from Slough and a station in Scotland are expected to afford valuable information regarding the range of atmospheric disturbances and to indicate whether those heard are mainly local or from a distance. The cathode ray D.F. apparatus will be used to determine the direction whence the X's originate.

All the above observations will be duplicated for two days before and the two days following the eclipse, in order to separate as far as possible those effects which normally occur at sunrise and sunset from those peculiar to the eclipse, and for this reason the experiments on all five days will continue for 2½ hours.

The R.S.G.B. is also arranging for a series of tests by its members on 90 metres, unmodulated, from a 1½kW station at Caterham, and for transmissions on other wavelengths from amateur stations in the South and North of England and probably from Iceland. Dr. W. H. Eccles, F.R.S., is also organising a series of observations by amateurs on the Continent.

The B.B.C. will announce later the special arrangements they propose making with regard to time signals, etc.

All these bodies of organised observers join in an urgent entreaty to listeners generally, and to amateur transmitters who are not actively engaged upon this special work, to avoid all risk of interference with the tests. Listeners are advised to confine their attention to their local station and not endeavour to reach out for distant stations, however interesting they may be. It is essential that oscillation should be avoided if full use is to be made of this rare and exceptional opportunity to conduct a series of important tests in the very short time available and the organised observers will be ever grateful to other wireless enthusiasts if they will show the true sporting spirit by leaving them in peace during the critical period.

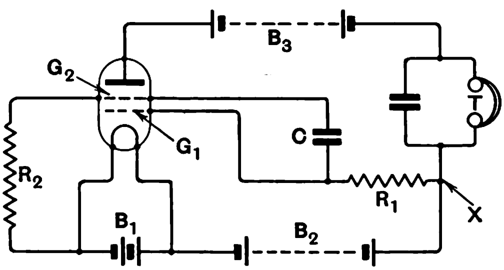
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

A MULTIVIBRATOR.

(*Application date, 9th February,* 1926. *No.* 267,279.)

A multivibrator circuit incorporating a four-electrode valve is described in the above British Patent by N. V. Philips' Gloeilampenfabrieken. The invention relates to the type of multivibrator circuit in which two three-electrode valves are

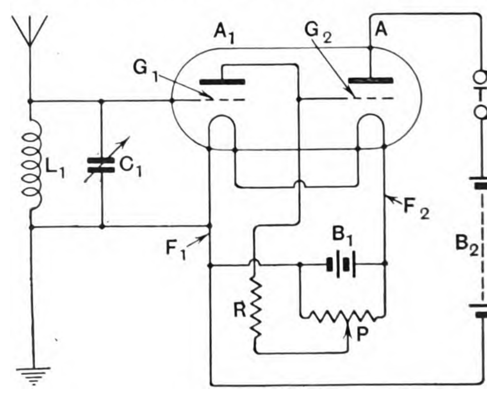


coupled together by means of a resistance, a retroactive effect being obtained by coupling the anode of the second valve to the grid of the first. Current impulses of large intensity are obtained in a circuit of this type due to the periodic charge and discharge of the coupling condenser, the frequency of the charging operation being determined by the time constant of the circuit constituted by the coupling condenser and the grid resistance. The present invention utilises a four-electrode valve in a somewhat similar manner, the method of connection being indicated in the accompanying diagram. Here the filament of the valve is heated by a battery B_1 while the anode circuit is supplied by a battery B_2 the anode being connected through telephones T or other indicating or coupling devices. Additional anode voltage is shown supplied by another battery B_3. At a point X in the anode circuit, that is, on the lower side of the telephones, connection is made to the inner grid G_1 through a resistance R_1. This grid is coupled through a condenser C to the other grid G_2, which is connected to the filament through a resistance R_2. The value of the coupling condenser may be of the order of 2,000 $\mu\mu$F, but may be made as large as one microfarad. The resistance R_1 is of the order of a few thousand ohms, while the resistance R_2 is approximately a megohm. The explanation of the operation of the device as given in the specification is as follows: The condenser C is charged first rapidly, and then gradually more slowly until a certain potential difference exists between its terminals. At this moment a rapid discharge will occur, accompanied, of course, by a reversal of the current. The condenser is then charged again in this manner, but in the opposite sense. It is stated that the low self-induction present in the connecting wires maintains this sequence of operations in somewhat the same manner as the flywheel allows the piston in a reciprocating engine to be carried just over top dead centre. The smaller the self-induction, the greater will be the tendency for the current curves of the discharge to differ from a sinusoidal wave form, and it will accordingly be more easy to sift out the higher harmonics and even, it is mentioned, those of radio frequency.

A LOW POTENTIAL AMPLIFIER.

(*Application dates,* 3*rd December,* 1925, *and* 4*th January,* 1926. *No.* 267,198.)

A low potential amplifier is described in the above British Patent by A. H. Midgley. The invention relates to a type of amplifier in which the anode of the first valve is given a very low positive potential, the grid of the next valve being connected to the anode. One form of the invention is shown in the accompanying diagram, in which the two valves are sealed together in one envelope, this being an additional feature of the invention. The illustration shows an ordinary aerial tuning circuit L_1 C_1 connected between the grid G_1 and filament F_1 of the first valve or, in this particular case, the first set of electrodes of the common valve. The anode A_1 is connected through a resistance R to a source of positive potential which is obtained through a potentiometer P from the filament heating battery B_1. The anode A_1 is connected to the grid G_2 of the second valve or second set of



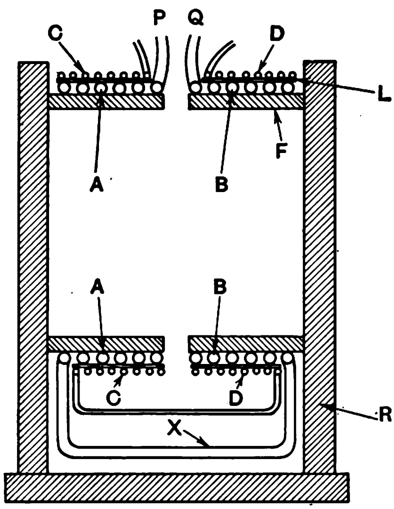
electrodes, while the anode A is connected through the telephone receivers T to a normal anode battery of reasonable voltage B_2. The value of the resistance R may be between a half and two megohms, while the positive potential communicated to the anode A_1 and grid G_2 through this resistance may be of the order of three or four volts. The specification states that the value of the resistance R may be increased to about five megohms, in which case the potential should be increased to about forty volts. It will be noticed that the two

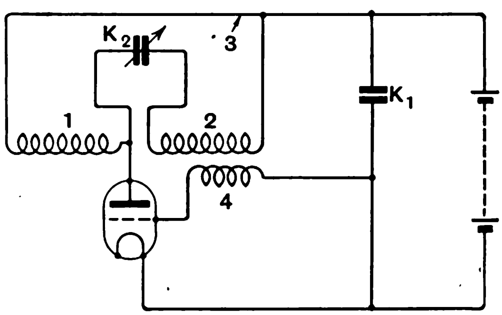
filaments F_1 and F_2 are shown connected in series. The specification also claims the use of a special valve incorporating two filaments, two anodes, and two grids, and details of this are given.

INDUCTANCE CONSTRUCTION.

(*Application date*, 30*th November*, 1925. *No.* 267,196.)

A type of inductance particularly useful for wavemeters is described by K. E. Edgeworth in the



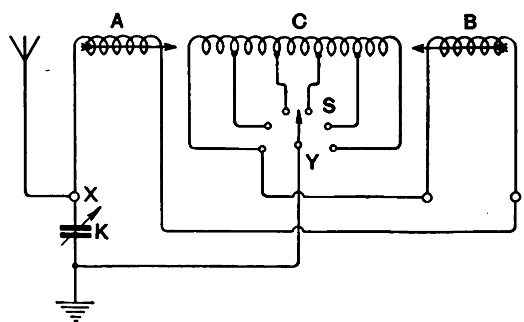


above Specification. The broad idea of the invention consists in winding the inductance in two portions, the extremities of which are connected together, while the inner ends are brought out for connection to the circuit with which it is to be used. This system can further be employed for coupling inductances or for transformer construction. The accompanying illustration shows two inductances coupled together, and constructed according to the invention, and also a wavemeter or generator circuit employing this type of coil. In the upper figure the first inductance comprises two portions *A* and *B*, wound on an insulating former *F*. The extremities of the winding are connected together by a wire *X*, while the adjacent ends *P* and *Q* are brought out for connection to the circuit. An insulating layer *L* is placed over the two windings *A* and *B*, while another inductance consisting of two portions *C* and *D* is wound over the layer *L*, being connected in a similar manner. The whole is arranged in a framework *R*. The lower illustration shows an inductance of this type connected in a wavemeter or valve generator circuit, the advantage of the arrangement lying in the fact that the earth connection to the inductances renders the system less liable to the influence of capacity effects. In the circuit the upper ends of the anode coil 1 and 2 are connected together at 3, and earthed through a blocking condenser K_1. The anode circuit is taken across the inner connections of the inductance by a condenser K_2. The grid coil 4 is shown coupled to the Section 2 of the anode inductance.

A TUNING ARRANGEMENT.

(*Convention date* (*France*), 29*th June*, 1925. *No.* 254,338.)

Compagnie pour la Fabrication des Compteurs et Material d'Usines a Gaz describes in the above British Patent an arrangement of mutually associated and electrically connected inductances, suitable for tuning over a large wavelength range, the novelty of the invention lying in the manner in which they are arranged so that the short wave sections are not appreciably influenced by the long wave sections. The accompanying drawing should make the invention quite clear. The short wave tuning coils are divided into two equal portions *A* and *B*, and are connected in series, but are spaced some distance apart. The two sections *A* and *B* are further so arranged that the directions of the windings are opposite. The longer wave tuning coil *C* is connected in series with the two short wave coils *A* and *B*, and is placed between them as indicated. The aerial and earth terminals are shown at *X* and *Y*, and the tuning condenser is shown at *K*, while a multiple switch *S* enables various tappings to be obtained on the longer wave portion. The specification states that the

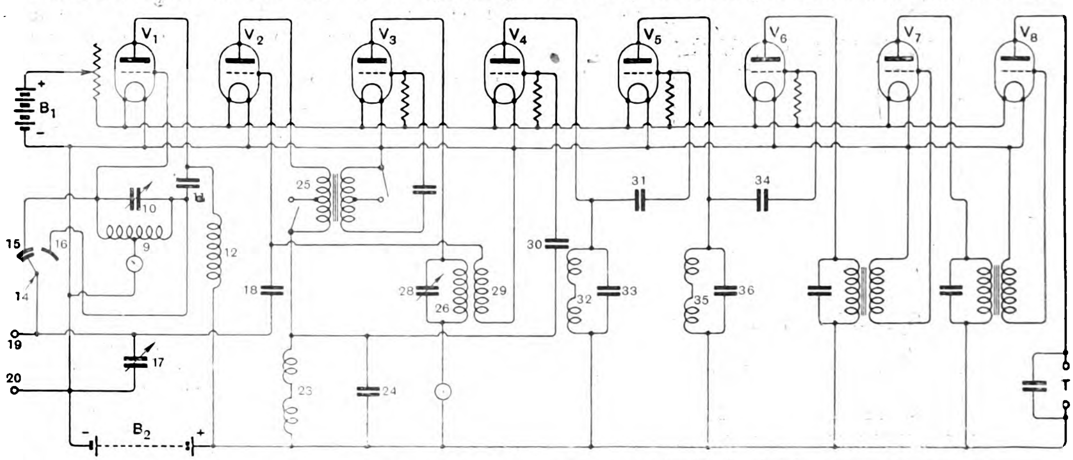


effect of the flux of the coil *A* upon *C* will be equal and opposite to the flux of the coil *B* upon the coil *C*, and, therefore, since the two coils *A* and *B* constitute the short wave portion the coil *C* will have no appreciable effect upon them.

STABLE SUPERHETERODYNE.

(*Convention date* (*France*), *12th December*, 1924. *No.* 244,484.)

The above Specification gives details of a superheterodyne receiver which has been produced by L. Levy. The accompanying diagram shows an eight valve set, the most important portions of which will be referred to in detail, but those components not mentioned may be taken as being quite normal, or simply a repetition of those in a preceding stage. The valves are shown as V_1 to V_8 V_1 is a local oscillator, V_3 and V_6 are detectors, while V_7 and V_8 are audio-frequency amplifiers, the output circuit of the last valve operating telephone receivers, or a loud-speaker T. Common batteries B_1 and B_2 are shown for the filament and anode supply respectively. The local oscillator is a shunt feed arrangement, and consists of a tuned circuit 9 10, and stopping condenser 11 and high frequency choke 12. A coupling condenser is provided with two fixed electrodes 15 and 16, and a movable electrode 14, the function of which will be described subsequently. A valve V_2 is arranged as a high and intermediate frequency amplifier. A frame aerial is used, and is connected at terminals 19 and 20, and is tuned by a condenser 17. The input is in series with the grid circuit of the valve V_2 together with a condenser 18 of small value and an air core inductance 29. The anode circuit of the intermediate amplifier V_2 contains the primary of a high frequency iron-cored transformer 25, and an intermediate frequency tuned circuit 23 24. The secondary of the iron-cored transformer 25 is connected between the grid and filament of the detector valve V_3. The anode circuit of the detector valve V_3 contains an intermediate circuit 28 26, coupled to the inductance 29. This tuned circuit 29 18 is tuned to a frequency which is considerably higher than the intermediate frequency, and is very tightly coupled to the intermediate circuit 28 26. The oscillatory circuit 23 24 is coupled through a condenser 30 to the grid of the amplifier V_4, a similar arrangement being employed in the subsequent amplifying valves. The specification states that the circuit operates in the following manner: The coupling condenser 14 15 16 enables the effect of the local oscillator upon the grid of the valve V_2 to be made as weak as may be necessary, since the potentials across the electrodes 15 16 are 180 degrees out of phase with respect to the common filament. The valve V_2 amplifies the radio-frequency oscillations, and the valve V_3 transforms them into beat frequency oscillations where they are returned by means of the coupling of 26 and 29 to the valve V_2 for amplification at intermediate frequency. The intermediate frequency voltages in the anode circuit of the valve V_2 are applied to the grid circuit of the valve V_4, and amplified by the valves V_4, V_5, and are finally detected by the valve V_6, after which low frequency amplification is carried out. Since the circuit 29 is tuned to a frequency which is high relative to the tuned circuits 23 24, 32 33, 35 36, the intermediate frequency amplification system is stable, and does not give rise to the production of continuous oscillations. A further refinement consists in placing the whole arrangement in a screened compartment to prevent the amplifier being influenced by stray fields.



EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. JULY, 1927. No. 46.

Editorials.

A new Type of Loud Speaker.

IN a letter to Professor Tait written in 1863, Lord Kelvin, as he afterwards became, referred to the fact that a condenser emitted a sound on being charged and discharged. Since that time many attempts have been made to develop condenser-telephones or, as they are sometimes called, electrostatic telephones. Ort and Riegger, two German scientists, published an article in 1907 describing some very interesting experiments on the subject, but no practical commercial instrument was evolved, able to compete with the wonderfully simple, small and effective electromagnetic telephone receiver. So long as the receiver was intended for use as an earphone it was necessarily very limited in size and weight and consequently in capacity, and the sounds emitted by it were feeble. For use as a loud-speaker, however, these limitations are of smaller moment, and it is not surprising to learn that research work has been carried on with the object of evolving an efficient condenser loud-speaker. The experiments to which we refer have been made by Dr. G. Green, of the Applied Physics Department of Glasgow University, and have extended over several years. They have been very successful, for we recently had the opportunity of hearing the reproduction of broadcast speech and music from some of Dr. Green's condenser loud-speakers. These were only experimental models, but the quality while not perfect, was surprisingly good.

The principle of the condenser loud-speaker is easily understood. It consists of a large condenser built up of alternate sheets of metal foil and paper. The dielectric separating the metal sheets will be partly paper, and partly the unavoidable air, which will act as a cushion when the plates are under voltage.

The metal sheets are connected alternately to the two terminals as in an ordinary condenser, and a steady P.D. of, say, 200 volts is maintained between the terminals. The electrostatic attraction between the plates will tend to compress the whole condenser, and if the back plate is fixed the front one will be moved towards it. If now an alternating P.D. is superimposed upon the steady P.D. the compression of the whole condenser will be varied and the front plate will move backwards and forwards, setting the air in vibration and emitting a sound having a pitch corresponding to the frequency of the applied alternating P.D.

If the alternating P.D. is obtained from the output circuit of an audio-frequency amplifier, the speech or music will be reproduced, but the quality of the reproduction will depend upon several factors.

The steady applied P.D. is the electrical analogue of the permanent magnet of the electromagnetic telephone receiver. It introduces no difficulty since, by suitable circuit

arrangement, it can be obtained from the H.T. battery of the amplifier, in fact it is only necessary to connect the condenser loud-speaker as a shunt across the battery and put a choke-coil in series with the battery so that the audio-frequency currents cannot pass through the battery, but are shunted round it through the condenser.

The mathematics of the subject have been published by Dr. Green in a paper entitled, "On the Condenser-Telephone," in the *Phil. Mag.*, for September, 1926, page 497, to which interested readers are referred

The experiments are being continued, and we look forward to this type of apparatus taking its place in the near future among high-class commercial loud-speakers.

Tramway Interference with Broadcast Reception.

BROADCAST reception in large towns is subjected to interference to a much greater degree than in the country. There is not only the proximity of a large number of receiving sets with the probability that some of them will oscillate at times, but electric motors and other electric apparatus, especially electro-medical apparatus, may cause serious interference, and electric tramways and railways in the immediate neighbourhood are known to cause trouble. The exact cause of this last named interference has been thoroughly investigated in Germany by the Post Office with the co-operation of the Berlin Tramway Company and the recently published results of the experiments are of great interest. The tests confirm the view of Burstyn that the trouble is due to damped oscillations set up by the interruption of the current passing from the overhead wire to the contact wheel or bow of the car. Contrary to what one might expect, however, no trouble is caused if the interrupted current is large, in fact, the current has to be less than about 2 amperes before any interference is caused by its interruption. Larger currents probably draw an arc between the separating metals and thus prevent the sudden break necessary to produce an oscillation. This peculiar effect explains why the interference is greater at night since then, even when the motors are switched off, there is the current taken by the car lighting, which amounts to something less than an ampere. With the car coasting at night every momentary interruption of the contact between the overhead wire and wheel breaks the lighting current and causes an oscillatory current which radiates a disturbance through the ether. One obvious, if somewhat wasteful, way of minimising the trouble is to connect a permanent leak in parallel with the lighting circuit so as to bring the total current above 2 amperes.

The trouble was found to be decreased whenever steps were taken to ensure a permanent smooth contact between the wire and wheel, thus preventing the interruptions of the current; relaying badly worn track, replacing worn overhead wire, using only freely rotating round wheels or smooth, broad-surfaced bows were all found to reduce the interference. Condensers connected between the collector-wheel and earth showed no marked improvement, but in some cases made matters worse. Since a current of 1 milliampere can cause considerable disturbance, leakage in the car wiring is important; in some cases the fact that the interference was as bad by day as by night was traced to this cause. Tests were made using different contact materials, but although carbon and zinc rubbing on copper were superior to other metals, the results did not lead to anything very practicable in this direction. The most promising direction in which improvement is to be looked for is in the design of trolley wheels kept in close contact with the wire by means of spring pressure acting on the trolley head itself. It is also stated that the trouble is eliminated by the use of properly designed and well maintained bow collectors as used in many Continental towns.

It will be interesting if those who live in the neighbourhood of tramway routes will keep notes of interference and try to correlate its intensity and frequency with the operation of the street cars.

Approximate Theory of the Flat Projector (Franklin) Aerial used in the Marconi Beam System of Wireless Telegraphy.

By Dr. J. A. Fleming, F.R.S.

IN the present Marconi system of Beam Wireless Telegraphy the projection of the wave and its confinement to a defined track is not accomplished by the use of a skeleton parabolic mirror with single aerial wire in the focal line as formerly, but is attained by means of a system of vertical aerial wires at equal distances and in one plane with a series of reflector wires behind in a parallel plane at a distance of one-quarter wavelength. The plane of the aerial wires is placed normally to a great circle line of the earth passing through the transmitting and receiving stations. These aerial wires are supplied with high frequency currents of exactly the same strength and exactly in phase with each other.

The distance between the aerial wires ($=d$) is made equal to half a wavelength or to some small odd multiple of half a wavelength. The distance between the reflector wires is the same or else half that between the aerial wires.

This type of aerial, as is well known, has been the subject of several important patent specifications by Mr. C. S. Franklin.

If stationary electric oscillations are set up in an aerial wire placed vertically to the earth's surface and if the frequency is so adjusted that the wavelength is equal to double the length of the wire, then electric radiation takes place which is a maximum in a plane at right angles to the wire and passing through its centre. If, however, harmonic oscillations are excited of greater frequency so as to create nodes and loops of potential and current on the wire, then, since the currents in adjacent half wavelengths are in opposite directions, these create opposing magnetic fields in the radiation and the effects at a distance on the median plane may be nullified.

Part of the inventions of Mr. Franklin have reference to means for suppressing the radiation from alternate stationary half wavelengths of the stationary waves on the wires, so that all the residual portions radiate waves which have their magnetic force in the same direction.

The result of this is equivalent to putting one on the top of the other a series of aerials each of which is half a wavelength long and radiate in step with each other, thus giving means for generating a very powerful electric radiation of short wavelength.

Concurrently with this the investigations and discoveries of Senatore Marconi have shown the important advantages of certain short wavelengths for long distance radio-telegraphy.

In one of Mr. Franklin's specifications a directive aerial is described comprising a number of vertical wires arranged parallel to each other and at equal distances in a plane perpendicular to the direction of propagation.

This aerial, under certain conditions of construction, has remarkable directive properties which appear to depend essentially on the phenomenon of wave interference.

The full mathematical discussion of this aerial is rather complicated and has not yet been given, but a certain reduced case can be treated without difficulty which shows why it is that such an aerial possesses these important directive properties.*

For the sake of simplicity the only case here considered is that in which each wire is supposed to be traversed by an electric current which is at any instant in the same direction all along the wire. The only region in which the radiation field is considered is in the equatorial plane of the wire and at a great distance.

Let Fig. 1 represent the plan of the aerial and its reflector wires on which the inter-

* The chief British patent specifications of Mr. C. S. Franklin on this subject are numbered Nos. 226246, 242342, 258942, 263943.

distance d may be taken as half a wavelength. Suppose that the point P is taken on the earth plane at such a large distance that lines drawn from P to the various aerial and reflector wires are very nearly parallel.

Let there be N such aerial wires and let γ be the distance from one end wire to the point P. Then the distances to the other aerial wires from P are respectively

$$\gamma,\ \gamma + d \sin\theta,\ \gamma + 2d \sin\theta, \text{ etc.}$$
$$\gamma + (N-1)\, d \sin\theta.$$

Where θ is the angle between the direction to P and the normal to the aerial plane.

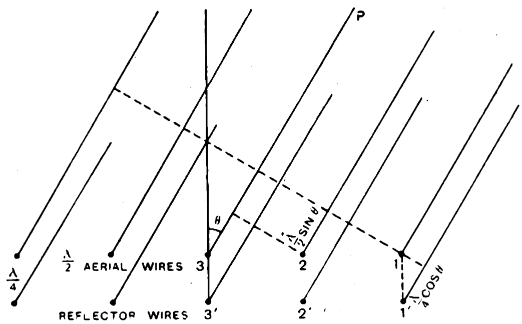


Fig. 1.

The magnetic field of each wire is propagated as a wave, and is also inversely proportional to the distance. Therefore at a distance γ and time t may be considered to be proportional to $\frac{1}{\gamma} \sin\,(m\gamma - nt)$ where $m = 2\pi/\lambda$ and $n = 2\pi/T$. T being the periodic time and λ the wavelength.

Since γ increases step by step as we go along the aerial we ought strictly to sum a number of terms of the type

$$\frac{1}{\gamma} \sin\,(m\gamma - nt),\ \frac{1}{\gamma + d \sin\theta} \sin\,[m\,(\gamma + d \sin\theta) - nt]$$

etc. But as the distance γ is very large compared with $(N-1)\ d \sin\theta$, we can consider the multiplier $1/\gamma$ to apply to each term and to be a constant. Also the direction at P of the magnetic field of each aerial wire is practically the same. Hence the resultant field at P is simply proportional to the sum of the terms

$$\sin\,(m\gamma - nt) + \sin\,[m\,(\gamma + d \sin\theta) - nt] + \text{etc.}$$
$$+ \sin\,[m\,(\gamma + \overline{N-1}\,d \sin\theta) - nt] \quad \ldots \quad (1)$$

By a well-known theorem the series

$$\sin\alpha + \sin\overline{\alpha+\beta} + \sin\overline{\alpha + 2\beta} + \text{etc.}$$
$$+ \sin\,(\alpha + \overline{N-1}\beta) \quad \ldots \quad (2)$$

is equal to

$$\frac{\sin\left(\alpha + \overline{N-1}\,\frac{\beta}{2}\right)\ \sin N\frac{\beta}{2}}{\sin\frac{\beta}{2}} \quad \ldots \quad (3)$$

In our case $\alpha = m\gamma - nt$ and $\beta = md \sin\theta$. Accordingly, if we sum the series of sines in (1) and call that sum H, we have

$$H = \sin\left[(m\gamma - nt) + (N-1)\,\pi\frac{d}{\lambda}\sin\theta\right]\frac{F}{G}$$

where

$$\frac{F}{G} = \sin\left(N\pi\frac{d}{\lambda}\sin\theta\right) \Big/ \sin\left(\pi\frac{d}{\lambda}\sin\theta\right) \quad (4)$$

and H is proportional to the magnetic field of all the aerial wire currents at P at a time t and distance γ.

In the next place we have to consider the effect of the reflector wires.

The current in the aerial wires is a simple sine curve current and creates a magnetic field of the same type. True radiation does not begin however until a distance of a quarter of a wavelength from the aerial wire. Hence the action of the current in the aeria wire on the reflector wire is a purely inductive action of its magnetic field.

When this field cuts the reflector wires it induces in them a secondary electromotive force proportional to the time rate of change of the field at that instant at the reflector wire.

Owing to the inductance of this reflector wire and its low resistance the electric current generated in it lags nearly $90° = \pi/2$ behind the inducing electromotive force in phase and as this inducing E.M.F. is 90° in phase behind the current in the aerial wire, it follows that the induced current in any reflector wire, as far as it is due to the current in the aerial wire just in front of it is 180° or π out of phase with it. In other words, the current induced in the reflector wire is in opposition as regards phase with that in the aerial wire in front of it. It may however be said that the current induced in each reflector wire is due to the currents in all the aerial wires to right and left, as well as to that wire exactly in front of it.

If, however, the aerial wires are spaced half a wavelength apart and the reflector wires also then a little consideration will show that the aerial wires, taken pair and pair on either side of one particular aerial wire, nearly neutralise each other's effect on the reflector wire immediately behind that particular aerial wire considered, since the distances of each of those pairs differs by nearly half a wavelength and therefore their propagated magnetic fields are in opposition as regards phase at the instant when they reach the reflector wire considered. Hence we may say that the current induced in any one reflector wire is for all practical purposes due only to the current in the aerial wire in front of it.

Since the aerial and reflector wires are only one-quarter of a wavelength apart and are long compared with that distance, the actual current induced in each reflector wire is not only in opposition as regards phase with the aerial wire current, but is practically equal to it in strength.

We have then to calculate the resultant field due to all the reflector wire currents at the point P. Referring to Fig. 1 it will be seen that the first reflector wire 1′ is at a distance from P equal to $\gamma + \frac{\lambda}{4} \cos\theta$ and that the second reflector wire is more distant than the first by a length $d \sin\theta$ if d is the interdistance of the reflector wires.

Taking account of the phase difference $T/4$ of the reflector wire current and E.M.F. creating it, we have the field at P due to the current in the first reflector wire proportional to

$$\sin\left[m\left(\gamma + \frac{\lambda}{4}\cos\theta\right) - n\left(t - \frac{T}{4}\right)\right]$$

or to

$$\sin\left[m\gamma - nt + \frac{\pi}{2}\cos\theta + \frac{\pi}{2}\right]$$

Also the distances of the reflector wires from P increase by steps $d \sin\theta$.

Hence, employing the same summation formula (3) as in the case of the aerial wire currents we have the total field H' at P due to the reflector wires given by

$$H' = \left[(m\gamma - nt) + \frac{\pi}{2} + \frac{\pi}{2}\cos\theta + (N-1)\,\pi\frac{d}{\lambda}\sin\theta\right]\frac{F}{G}$$

where

$$\frac{F}{G} = \frac{\sin\left(N\pi\frac{d}{\lambda}\sin\theta\right)}{\sin\left(\pi\frac{d}{\lambda}\sin\theta\right)} \quad \ldots \quad (5)$$

Since the current in the reflector wires is opposite in phase to that in the aerial wires we have to subtract (algebraically) H' from H to obtain the resultant current. The above formulæ are difficult to employ arithmetically except with certain limitations.

We shall, in the first place, consider that the reflector wires and aerial wires are both spaced apart by half a wavelength so that $d = \lambda/2$ and hence

$$\pi\frac{d}{\lambda}\sin\theta = \frac{\pi}{2}\sin\theta.$$

Also, to avoid merely mathematical difficulties, we shall suppose that the distance λ is an odd multiple of a quarter of a wavelength, so that

$$\gamma = \frac{\lambda}{4} + l\lambda$$

Where l is some integer.

Also we must select some epoch of time, and we shall assume that $t = kT$ where k is some integer and therefore $\cos nt = 1$ and $\sin nt = 0$.

In the next place we shall abbreviate these formulæ by writing

$$\sin\left(N\frac{\pi}{2}\sin\theta\right) = F\,;\ \sin\left(\frac{\pi}{2}\sin\theta\right) = G\,;\ m\gamma = L\,;$$

$$\frac{\pi}{2} + \frac{\pi}{2}\cos\theta = K \text{ and } L + F - G = X$$

$$L + F - G + K = Y.$$

The formulæ (4) and (5) then become

$$H = \sin(X - nt)\frac{F}{G}\,;\ H' = \sin(Y - nt)\frac{F}{G}$$

and

$$H - H' = \frac{F}{G}\left\{\sin(X - nt) - \sin(Y - nt)\right\} \quad (6)$$

Expand the contents of the bracket in (6) and we have,

$$\sin X \cos nt - \cos X \sin nt - \sin Y \cos nt + \cos Y \sin nt$$

or

$$(\sin X - \sin Y)\cos nt - (\cos X - \cos Y)\sin nt.$$

For the epoch considered, viz., $t = kT$ when $\cos nt = 1$, $\sin nt = 0$, this reduces to

$$H - H' = \frac{F}{G}\left\{\sin X - \sin Y\right\} \quad \ldots \quad (7)$$

We have then reduced the formula to a condition in which it can be used arithmetically to predetermine the field of this flat aerial at a distance great compared with its linear dimensions.

For this purpose we shall assume that $N=30$, that is, that there are 30 aerial wires spaced half a wavelength apart.

The first thing is to calculate a table giving the value of F/G for various angles (θ) from 0° to 90° and for $N=30$.

This is given in Table I.

The next step is to calculate for the same constants the value of $\sin X$ and $\sin Y$.

And take their algebraic difference. This is done in Table II for various values of θ.

Meanwhile we can see at once the nature of the radiation in three directions.

(i.) As regards the forward direction perpendicular to the plane of the aerial. In this case $\theta=0$. Hence we have

$$\sin\frac{\pi}{2} - \sin\frac{3}{2}\pi = 2.$$

For the same value $\theta=0$, we have $F/G=N$. Therefore the radiation in a forward direction is proportional to 2 N or to 60.

(ii.) In the next place consider the backward direction. Then $\theta=180°$ $\sin\ \theta=0$, $\cos\ \theta=-1$, hence the radiation is

$$\sin\frac{\pi}{2} - \sin\ \frac{\pi}{2} = 0.$$

There is therefore a complete projection of the radiation forward and a complete prevention of all radiation in the backward direction.

Since radiation and absorption are always proportional it follows that such an aerial absorbs all rays coming straight towards the aerial and prevents all waves from reaching the aerial from behind the reflector. The

TABLE I. $N=30$.

θ	$\sin\theta$	$\frac{\pi}{2}\sin\theta$	$N\frac{\pi}{2}\sin\theta$	$\sin\left(\frac{\pi}{2}\sin\theta\right)$	$\sin\left(N\frac{\pi}{2}\sin\theta\right)$	Ratio F/G $\dfrac{\sin\left(N\frac{\pi}{2}\sin\theta\right)}{\sin\left(\frac{\pi}{2}\sin\theta\right)}$	θ
0°	0	0	0	0	0	30.0	0°
1°	.0174	1° 34′	47°	.0276	.7316	26.5	1°
2°	.0349	3° 8′ 27″	94° 13′ 48″	.0550	.9972	18.0	2°
3°	.0523	4° 42′ 25″	141° 12′ 36″	.0820	.6260	7.6	3°
3° 30′	.0610	5° 30′	165°	.0958	.2588	2.7	3° 30′
4°	.0697	6° 16′ 23″	188° 11′ 24″	.1090	—.1427	—1.3	4°
4° 30′	.0784	7° 3′	211° 42′	.1227	.5249	—4.3	4° 30′
5°	.0871	7° 50′ 20″	235° 10′ 12″	.1363	—.8208	—6.02	5°
10°	.1736	15° 37′ 26″	468° 43′	.2686	.9469	3.52	10°
15°	.2588	23° 17′ 31″	698° 45′ 36″	.3960	—.3624	—0.91	15°
20°	.3420	30° 46′ 48″	923° 24′	.5113	—.3960	—0.77	20°
25°	.4226	38° 20′ 24″	5141° 1′ 12″	.6202	8.746	1.41	25°
30°	.5000	45°	1350°	.7070	—1.000	—1.414	30°
35°	.5736	51° 37′ 26″	1548° 43′ 12″	.7840	.9469	1.21	35°
40°	.6428	57° 51′ 6″	1735° 33′ 36″	.8465	—.9018	—1.06	40°
45°	.707	63° 38′	1908° 54′	.8962	.9460	1.05	45°
50°	.766	68° 56′ 24″	2068° 12′	.9330	—.9994	—1.07	50°
60°	.866	77° 56′ 24″	2338° 12′	.9778	.0320	.032	60°
90°	1.000	90°	2700°	1.000	0°	0°	90°

We shall assume that

$$\gamma = \frac{\lambda}{4} + l\lambda$$

where l is some integer.

Hence $m\gamma = \frac{\pi}{2} + l2\pi$. Since $m = 2\pi/\lambda$.

We have then to obtain the numerical values of

$$\sin\left[\frac{\pi}{2} + \frac{N-1}{2}\pi\sin\ \theta\right]$$

and of

$$\sin\left[\frac{\pi}{2} + \frac{\pi}{2} + \frac{\pi}{2}\cos\ \theta + \frac{N-1}{2}\pi\sin\ \theta\right]$$

combination is, in fact, a perfectly "black body" on the aerial surface and a perfectly opaque or reflecting body on the opposite side.

Moreover, the reflection from the reflector wires strengthens the effect in the aerial when used as a receiver.

(iii.) In the third place, let us consider the radiation along the plane of the aerial wires that is for $\theta=90°$. Then $\sin\theta=1$ and $\cos\theta=0$.

The value of F/G or of

$$\sin\left(N\frac{\pi}{2}\sin\theta\right)\Big/\sin\left(\frac{\pi}{2}\sin\theta\right) \text{ for } \sin\theta=1$$

can be found as follows :—

It is shown in books on trigonometry that

$$\frac{\sin N\phi}{\sin\phi}=N\cos\phi\left(1-\frac{N^2-4}{L^3}\sin^2\phi\right.$$

$$+\frac{(N^2-4)(N^2-16)}{L^5}\sin^4\phi$$

$$-\frac{(N^2-4)(N^2-16)(N^2-36)}{L^7}\sin^6\phi\cdot\text{etc.}$$

If $\sin\phi=1$ and $\cos\phi=0$, then $\sin N\phi/\sin\phi$ is zero when ϕ is 90°.

Therefore the value of F/G is zero for $\theta=0$. In other words, there is no radiation in the direction of the plane of the aerial.

To obtain the radiation in other directions we have to consult Table II, which gives it for various values of θ, and the last column gives a series of numerical values which may be taken to be proportional at a given distance from the aerial of either the magnetic or electric force in the wave in that azimuth. This radiation intensity for various angular deflections is plotted graphically in Fig. 2.

TABLE II. $m\gamma=\frac{\pi}{2}+l2\pi=L$

θ	X $\frac{\pi}{2}+\frac{N-1}{2}\pi\sin\theta$	K $\frac{\pi}{2}+\frac{\pi}{2}\cos\theta$	Y $\frac{\pi}{2}+\frac{\pi}{2}+\frac{\pi}{2}\cos\theta+\frac{N-1}{2}\pi\sin\theta$	$\sin X-\sin Y$ $\sin\frac{\pi}{2}+\frac{N-1}{2}\pi\sin\theta-\sin\left[\pi+\frac{\pi}{2}\cos\theta+\frac{N-1}{2}\pi\sin\theta\right]$	$\frac{F}{G}$ From Table I.	Radiation $=\frac{F}{G}(\sin X-\sin\gamma)$	θ
0°	90°	180°	270°	2	30	+60	0°
1°	135° 26′	180°	315° 26′	1.4	26.5	+37.1	1°
2°	181° 5′ 21″	180°	361° 5′ 11″	—0.038	18.0	— 0.68	2°
3°	226° 30′ 11″	180°	406° 30′ 11″	—1.45	7.6	—11.0	3°
3° 30′	249° 30′	180°	429° 30′	—1.87	2.7	— 5.05	3° 30′
4°	271° 55′	180°	451° 55′	—2.0	— 1.3	+ 2.6	4°
4° 30′	294° 39′	180°	474° 39′	—1.82	— 4.3	+ 7.8	4° 30′
5°	317° 20′	180°	497° 20′	—1.36	— 6.0	+ 8.16	5°
10°	543° 5′	177° 20′	720° 41′	+0.042	3.52	+ 0.15	10°
15°	765° 28′	177°	942° 28′	+1.39	— 0.91	— 1.26	15°
20°	982° 37′	174° 30′	1157° 7′	—1.96	— 0.77	+ 1.51	20°
25°	1192° 40′ 48″	171° 30′	1364° 11′	+1.89	1.41	+ 2.66	25°
30°	1395°	168°	1563°	—1.54	— 1.41	+ 2.18	30°
45°	1935° 16′	153° 36′	2068° 52′	+1.71	1.05	+ 1.79	45°
60°	2350° 15′	135°	2485° 15′	+0.4	0.032	+ 0.013	60°
90°	2610°	90°	2700°	+2.0	0	0	90°

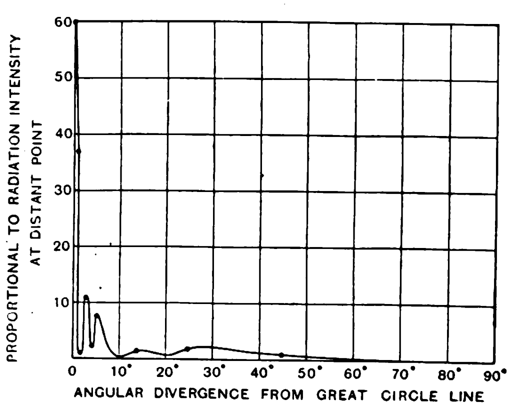


Fig. 2.

Now one thing shows itself at once from these figures, and that is the rapid rate at

which the radiation falls off for a very slight angular deviation from the great circle or normal line. Even two degrees deviation in the case considered drops it from 60 to 0.68. In other words, the beam is very sharply defined. At a distance of 3,000 miles a length of 100 miles subtends an angle of 2°. Therefore, such a beam should not spread at 3,000 miles over more than 100 miles, without falling to zero on either side. As a matter of fact this is found to be the case.

The next thing which is striking is that after falling off to nearly zero at 2° deviation, the radiation recovers again a little, for greater deviation, and falls again to nearly zero for 10° deviation. Beyond 10° it again rises and then falls nearly to zero at 60° and quite to zero at 90°.

Thus there are a series of directions of nearly zero radiation with intermediate directions of decaying maxima. In short, there are a series of *interference bands* just as shown in optical experiments.

Each of the aerial wires is, in fact, like an incandescent filament sending out monochromatic radiation.

There is a well-known experiment of Thomas Young in which two small holes or slits in a metal plate placed very close together are illuminated from behind with monochromatic light. On a white screen placed a little way in front of the slits are then seen a series of bright and dark bands called interference bands. A point in front at equal distance from both slits is a bright band region. A little way on either side, such that the distances from that point to the two slits differ by half a wavelength or an odd multiple of half a wavelength, there is a dark band with bright bands in between.

There appears to be an exactly similar effect in the case of a Franklin flat projector aerial as above described. This is predicted theoretically, and it could be tested practically by a ship with a single vertical aerial wire moving transversely across the great circle line of projection of such an aerial and ascertaining at what distances from that central line the wireless signal strength dies away and revives again at rather farther distances. It has been found by experiment that such interference bands as predicted theoretically do actually exist in the case of this flat projector aerial. It has generally been the custom to plot the radiation diagrams of projection aerials in polar form, as may be seen from the diagrams in the Papers read by Senatore Marconi to the Royal Society of Arts in the July 25th, 1924, and December 26th, 1924, issue of their Journal.

The plotting in rectangular form as here given brings out rather better the *interference effects* which present themselves in these cases and are responsible for the sharply marked beam properties of these grid aerials.

Laboratory Note.

An improvement on the "Double Click" method of measuring the resonant wavelength of a circuit.

THE wavelength of a circuit, such as a coil with a condenser connected across its terminals, may be measured by the well-known "double click" method, the chief advantages of which are that no subsidiary apparatus need be connected to the circuit under test, and that an oscillating wavemeter ("heterodyne" wavemeter) is the only instrument required.

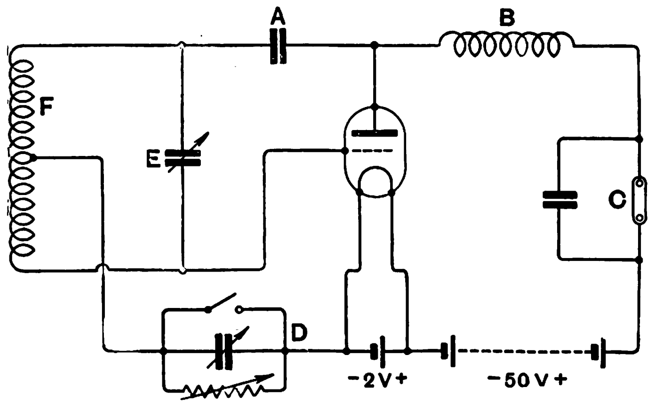
The usual method is to bring the circuit to be tested near a valve wavemeter, emitting C.W., in the anode circuit of which phones are connected; on rotating the wavemeter condenser through the resonant wavelength of the circuit under test, clicks are heard in the phones, and it is then assumed that the reading of the wavemeter midway between the clicks is the wavelength required. The method has two disadvantages: first, the clicks only occur when the circuit

under test is fairly tightly coupled to the wavemeter, which is liable to cause appreciable error in the wavemeter readings; secondly, when the coupling is reduced as much as possible to reduce the error, the clicks are very faint, and can only be distinguished with difficulty.

By the use of the grid-leak interrupter effect described by F. M. Colebrook* a much louder indication of resonance may be obtained, with looser coupling.

the usual method, it can literally be done "with the phones on the table"; and owing to the looser coupling that we can now use, there is less likelihood of the wavelength of the meter being affected by the proximity of the circuit under test.

If the coupling between test circuit and wavemeter is further loosened, the buzz of the interrupter does not completely stop when the resonant wavelength is passed through, but the note of the "buzz" changes,



Circuit of heterodyne wavemeter.

The figure shows the diagram of Mr. Colebrook's wavemeter, in which *D* represents the interrupter device. By reducing the capacity of the interrupter condenser, a point will be found where the interruptions cease, and on increasing the capacity they will start again. Adjust the condenser until the interruptions only just restart (the adjustment alters with change of coil *F* of wavemeter), place circuit to be tested near the wavemeter, and rotate wavemeter condenser through the resonant wavelength of the circuit under test, when it will be found that the interruptions suddenly cease over a portion of the wavemeter scale roughly corresponding to the space between the "clicks" of the usual method. By loosening the coupling between wavemeter and test circuit, the width of this "silent space" can be reduced to about half a scale division of the wavemeter. The "silent space" is much easier to hear than the "clicks" of

it becomes "woolly" and drops a semitone or two. The wavemeter condenser should have some form of fine adjustment, or this may be missed, as it only occurs over a very small portion of the scale. The interrupter condenser needs careful adjustment to produce the effect with the minimum possible coupling. A little practice is needed to distinguish the flattening of the "buzz" note, it is not so obvious as the complete cessation of sound with closer coupling, but it is far easier to distinguish a change of pitch of a loud note than it is to hear the very faint "click" of the usual method.

While no measurement of this sort can claim to very high precision, it is suggested that the use of the Colebrook interrupter in the manner described increases the convenience of the method considerably, it should also increase the accuracy owing to the looser coupling employed; a probable error of ½ to 1 per cent. may be expected, which approaches the inaccuracy of a commercial wavemeter.

C.R.C.

* "Design for a Wavemeter," *Wireless World*, 6th October, 1926, p. 481.

The Exact and Precise Measurement of Wave-length in Radio Transmitting Stations.

By RAYMOND BRAILLARD, Engineer A. & M., E.S.E., Advisory Engineer of Radio-Belgique, President of the Technical Commission of the Union Internationale de Radiophonie; and EDMOND DIVOIRE, Engineer A.I.Br., in charge of classes at Brussels University, Secretary of the Technical Commission of the Union Internationale de Radiophonie.

(*Continued from page* 330 *of June issue.*)

Description of Wavemeter (*continued*).

B. Indicator Circuit.

In order to form an idea of the way in which the adopted arrangement behaves, it is useful to place the problem in equation form.

Fig. 4 shows the resonant circuit, Circuit No. I, and the indicator circuit, Circuit No. II.

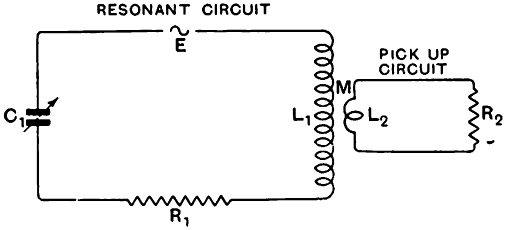


Fig. 4.

We will call E the effective electromotive force in the resonant circuit; we will say that it is constant, seeing that in principle the reaction of the wavemeter on the transmitting station to be measured should be negligible.

We will also assume that the direct induction between the transmitter and the indicator circuit is inappreciable (which is true) and consequently that there is no electromotive force acting in this circuit other than that induced by the primary (resonant circuit).

We will call M the coefficient of mutual inductance.

Under these conditions, the equations of electrical equilibrium of the two circuits read as follows, adopting imaginary annotations for the purpose :—

$$E = I_1\left[j\left(L_1\omega - \frac{I}{\omega C_1}\right) + R_1\right] + M\omega j I_2$$

$$O = I_2[jL_2\omega + R_2] + M\omega j I_1$$

Whence we derive, eliminating I_2 :—

$$E = I_1\left[j\omega\left(L_1 - L_2\frac{M^2\omega^2}{L_2^2\omega^2 + R_2^2}\right) - \frac{j}{\omega C_1} + \left(R_1 + R_2\frac{M^2\omega^2}{L_2^2\omega^2 + R_2^2}\right)\right]$$

The coefficient $j\omega I$ is *the apparent self-inductance of Circuit No. I*; it is composed of two terms: L_1, self-inductance, properly so called, of such circuit, and

$$L_2\frac{M^2\omega^2}{L_2^2\omega^2 + R_2^2},$$

which, representing the supplementary self-inductance carried into I by the reaction of II, we will call *equivalent self-inductance of Circuit II.*

Likewise,

$$R_1 + R_2\frac{M^2\omega^2}{L_2^2\omega^2 + R_2^2}$$

the *apparent resistance* is made up of Circuit I's own resistance and the equivalent resistance of Circuit II.

L_1, R_1 and C_1, being defined as we have said above, we have now to find what are the most favourable values of R_2, L_2 and M.

The first consideration is that of decrement; it is necessary that the equivalent resistance of Circuit II should be as low as possible.

Now, in examining its expression

$$R_2 \frac{M^2\omega^2}{L_2^2\,\omega^2 + R_2^2}$$

we see that it is necessary to have M small and L_2 large. As for R_2, we may bear in mind that, for R_2 varying from 0 to infinity, the above expression starting from 0 will go through a maximum corresponding to the equality of the two terms of the denominator to revert again towards 0.

There are, therefore, two interesting solutions; but there is a further consideration which is more important for a wavemeter, and that is the necessity of a strict constancy of standardisation.

Now, the value of R_2 does not always remain constant; we know, as a matter of fact, that on one hand the resistance of a lamp of the four-volt type varies with intensity of current flowing through it (it may go from 3 to 4 ohms at dark red to 7 to 8 ohms at bright red). On the other hand, if we use thermoelectric couples the replacing of one couple by another gives rise almost inevitably to differences in resistance.

It is necessary, therefore, to ward off such variations and consequently to choose for R_2, L_2 and M values such that they should give above all a self-inductance equivalent to Circuit II as little dependent as possible on R_2.

The equations permit us to draw the equivalent resistance and self-inductance curves as a function of R_2 for various values of M and L_2, and we can thus form an approximate idea of the most favourable values to be adopted.

Nevertheless it has been deemed prudent not to be content with this theoretical tracing and to plot the curves in question experimentally.

We will not enter into details of this work, which is long and critical, in view of the extremely low variations of resistance and self-inductance which we have to measure; we know the difficulties involved in these high frequency measurements.

We will confine ourselves to pointing out that the measuring instrument used was an amplifying triode voltmeter of the type built by the Cambridge Instrument Co., under the name of the Moullin voltmeter. This instrument, which is a very sensitive one, has the great advantage of not affecting in any great degree the circuit characteristics. All we need bear in mind is its resistance.

For measuring resistance a concurrent use is made of the method known as "resistance variation" including in the circuit different known resistance values, and the method known as "reactance variation" making use of the properties of the resonance curve where such is possible, that is to say, when circuits comprise a variable condenser.

We will not enlarge on this work, which is well known.

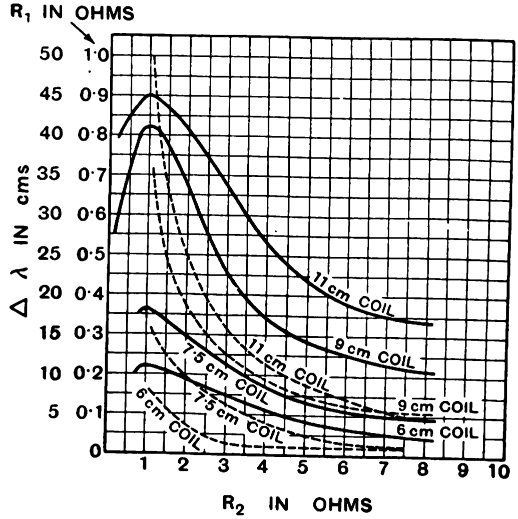


Fig. 5.

We give, by way of example, in Fig. 5 the results of measurement of the frequency of 1,130,000 cycles (265.5 metres wavelength).

We there differentiate between the curves giving the value of equivalent resistance of Circuit II acting on R_1—which is the proper resistance of such a circuit and shows a maximum, as has already been foreseen—and curves giving the value, not of self-inductance but rather the increase of wavelength, involved in the wavelength of Circuit I by the presence of Circuit II (these different curves are plotted as a function of R_2).

These curves have been drawn for various diameters of winding, forming the inductance L_2—the distance between the two coils remaining constant.

The values of M and L_2 have not been measured in each case, but they are of the order of 1 to 3 microhenries.

The value of R_1 is about 3 to 5 ohms, that of L_1 105 microhenries.

The examination of these curves shows that for a winding of 7.5 centimetres diameter (value adopted) a variation of R_2 between 4 and 7 ohms involves a variation of wavelength lower than 2.5 centimetres or 1/10,000 of the wavelength to be measured. As for the supplementary resistance brought into the circuit it is lower than 0.15 ohm and does not vary more than 0.05 ohm. It is obvious that we might have been able by increasing R_2 in some way or another, or by diminishing L_2 and M, to get even better conditions. But we must not lose sight of the fact that a diminution of current I_2 would be the result, perhaps sufficient to stop the lamp from glowing even at a dull red. This could only be got over by tighter coupling to the transmitter, which would involve undesirable reactions.

The wavemeter, being intended eventually to measure the wavelength of stations not having more than 200 watts power, and the 3.5-volt glow lamp requiring a current of 100 to 150 milliamperes to heat the filament to dark red, we must therefore confine ourselves to these limits.

Let us point out in passing that the thermocouples supplied with wavemeters have a resistance on the high frequency side of 5 to 7 ohms, approximately equivalent therefore to the resistance at dull red heat of the filament of a pocket lamp, which ensures constancy of standardisation no matter what system of indicator be used.

C. *Method of Standardisation—Precision of Measurements.*

Standardisation of these wavemeters has been carried out in absolute values by means of a method derived from the use of an instrument studied by Messrs. Abraham and Bloch* and well known under the name of "multivibrator."

We tune the fundamental frequency of the multivibrator to a tuning fork. This tuning fork as a rule produces the note C″ (1,024 periods). Another triode oscillator of any given type is tuned in by the beat-method to successive harmonics of the multivibrator. We thus get a series of known frequencies which we can use to standardise the wavemeter.

Should the multivibrator not produce sufficiently high harmonics the operation indicated above is repeated using an ordinary heterodyne. In this case the first heterodyne plays the part of a multivibrator with a high fundamental frequency, and a second heterodyne serves to select harmonics by the beat-method.

It is this last-named procedure which we have used, seeing that the frequencies which interest us extend from 500,000 to 1,500,000 cycles, while the multivibrator does not allow of use being made of harmonics above the 175th or a frequency of 175,000 approximately.

Arrangements Used. (See Figs. 6 and 7.)

We do not propose to describe in detail the apparatus used; we will confine ourselves to giving a few short notes as to the precautions taken to secure an accuracy of standardisation of the order of 1/10,000.

(*a*) *Tuning Fork and Multivibrator.*

Generally it is sufficient to compare from time to time the fundamental note of the multivibrator with that of the tuning fork by the beat method.

There is a risk of the fundamental period of the multivibrator varying a little, in the interval between tests, due to batteries dropping in voltage, etc. That is why we have used a method already described, which consists in maintaining the multivibrator in synchronisation with the tuning fork during the whole working time, by the following procedure :—

The tuning fork is kept vibrating by one or several triodes in the well-known way, and the secondary of a transformer connected in the plate circuit of the multivibrator. The primary of the transformer is connected in the plate circuit of one of the several triodes used to maintain the vibration of the tuning fork. In this way, when the multivibrator is adjusted approximately to the tuning fork frequency, a synchronising effect occurs which tends to pull into step the fundamental frequency of the former, this effect occurring even within broad limits of mistuning.

A word of precaution, however, is necessary. The maintaining of a tuning fork by a triode gives rise to a very slight variation

*See description in the book "High Frequency Measurements" by Armagnat and Brilloin.

of its natural frequency. That is why we compare, from time to time, the note of the maintained fork with that of a fork mounted on its resonance case, *which forms the real standard instrument.*

We have thus been able to observe that, due to the heating of maintenance triodes, the period of the maintained fork may vary by several points in 100,000.

We have thought it to be indispensable to carry out an experimental test of the theory, and we have carried out a series of tests at different temperatures: these showed that the theoretical law was correct, at least within very wide limits (from 15 to 25 degrees Centigrade approx.).

We have therefore enclosed the maintained fork and the standard fork, used as a

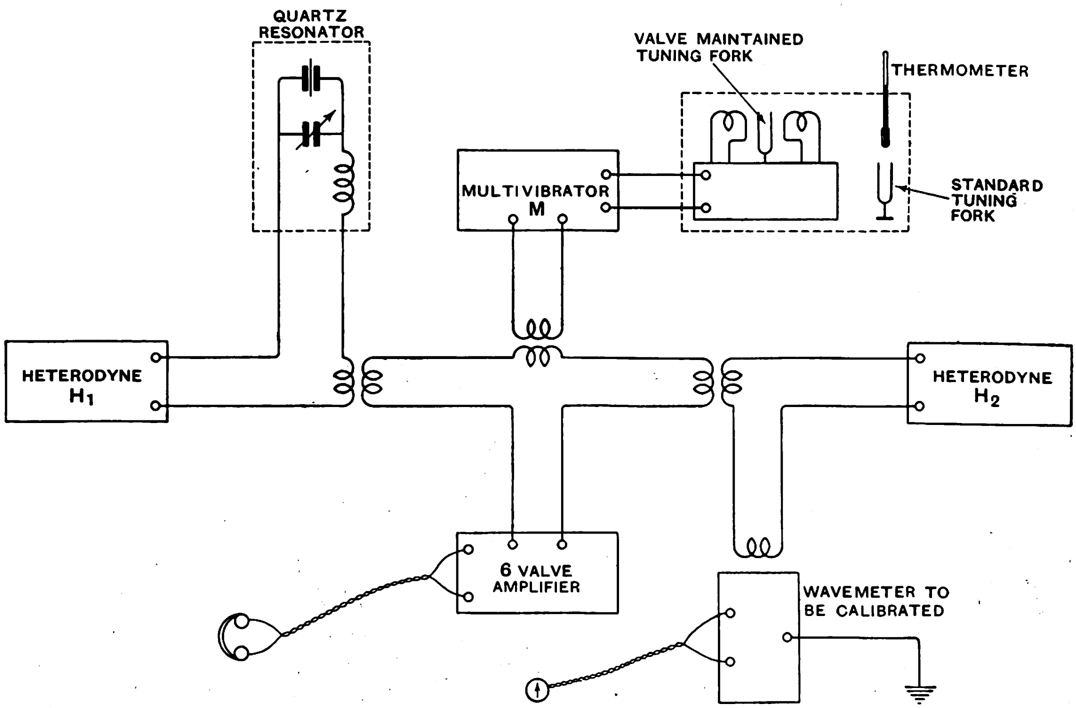


Fig. 6. *Circuit arrangement used for wavemeter calibration.*

check, in a case lagged internally with a thick layer of felt so as to keep a uniform and sufficiently constant temperature during measurement. This case was fitted with a thermometer so that it was convenient to read the temperature and deduce therefrom the corresponding correction coefficient.

The standard fork, whose frequency is 1,024 (C″) has been standardised to within 1/10,000 at the Conservatoire of Arts and Crafts. It is of steel, as we have not had time to get a special fork made of alloy with a very small coefficient of expansion, and we must therefore allow for a certain working temperature variation.

Theory shows that the period of a fork is inversely proportional to the square root of the coefficient of elasticity, this varying with temperature according to a linear law, at least within the limits which interest us, and that the coefficient of variation is of the order of 2.4/10,000 per degree Centigrade; whence it results that the period varies 1.2/10,000.

Local Oscillators H_1 and H_2.

These two instruments are completely screened, so as to avoid stray effects which might modify the transmitting constancy; the control condensers have geared-down controls. As a means of control we have coupled up to H_1 a piezo-electric resonator of the Loewe luminous quartz crystal type.

This resonator has been standardised to 2/10,000 by the Reichsanstalt Laboratory, Berlin.

The principal use of this resonator is to test, from time to time, by a rapid method, the yield of harmonics of the multivibrator.

The beats between these harmonics and the fundamental waves of H_1 and H_2 are picked up and amplified by an arrangement consisting of a 4-stage resistance-coupled amplifier of the Brillouin type, followed up by a 2-stage L.F. amplifier.

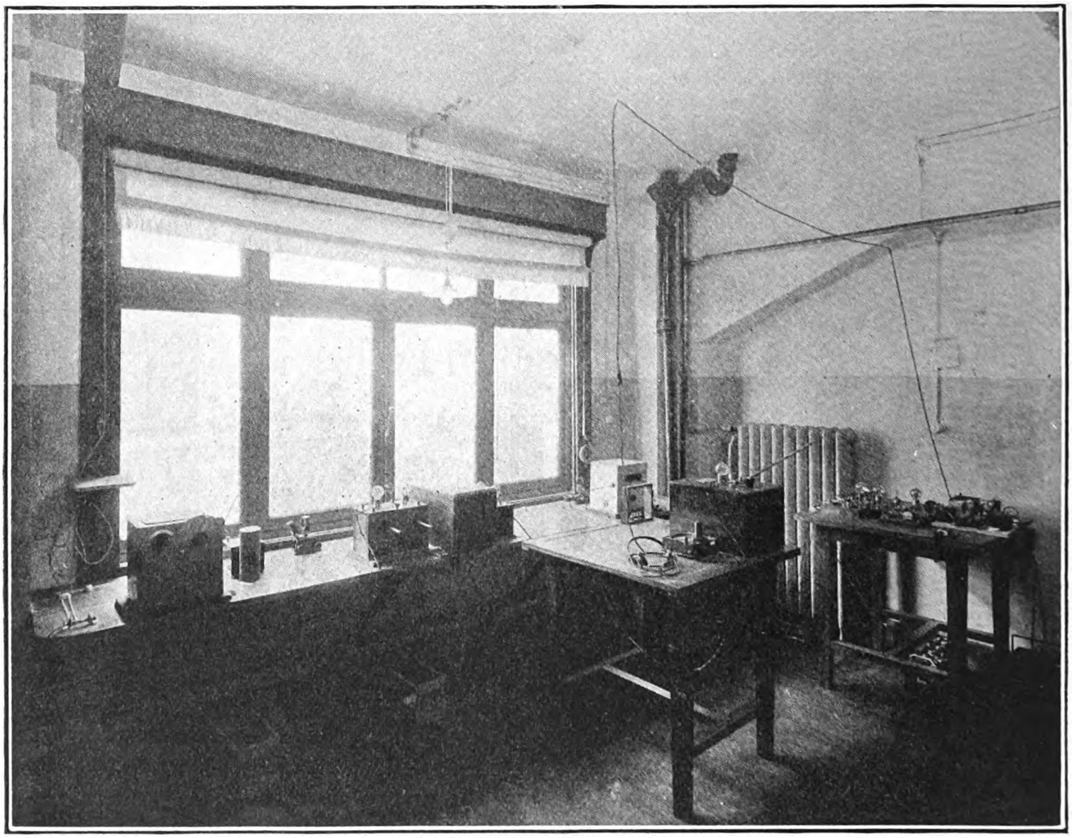


Fig. 7. *A corner of the laboratory arranged for wavemeter calibration.*

This amplifier is sufficiently sensitive to pick up, without much difficulty, beats of the order of 4 to 10 per second, either side of the silent point of the beat between M and H_1, and beats of the order of 50 to 100 covering the silent point between H_1 and H_2.

We are accustomed to carry out these measurements by keeping the various instruments working simultaneously, so as to ensure that inevitable reactions between circuits may not modify the period of the two others, if one of the oscillators is switched off.

This method of procedure requires much attention and a certain amount of experience in beat measurements, but it has the great advantage of allowing a constant control of experimental conditions and so avoiding certain causes of error.

Standardisation of Wavemeter on Fundamental Wave H_2.

The indicator circuit of the wavemeter is fitted up with a thermocouple having an H.F. resistance of 7 ohms (corresponding therefore to the normal working resistance), and of

which the sensitiveness is 5 millivolts on open circuit for 20 milliamps H.F.; the galvanometer used was of the Cambridge unipivot type.

We can in this way get a long extension lead to the measuring instrument without any appreciable reaction on hererodyne H_2.

The resonance point is not found by observing the peak of the resonance curve, which is always a trifle inaccurate, but by finding two points of equal amplitude on either side of it, a procedure which gives all the accuracy desired and can be adopted, thanks to the stability of working of H_2.

Accuracy of Wavemeter Standardisation.

Different causes of error arise as follows :—

(*a*) That due to standardisation of the tuning fork.

The error due to the tuning fork is lower than 1/10,000, according to certified standardisation.

(*b*) That due to inaccuracy of successive operations above described for producing a standardised wave.

The production of a standardised wave comprises several operations :—

1. Reading the thermometer with a view to estimating the temperature correction, the accuracy being about 0.2° C. This, therefore, gives us an error of 2/100,000 in estimating the frequency.

2. "Pulling" of multivibrator by maintained fork; error, 0.

3. Tuning of H_1 on a harmonic of multivibrator. Approximate error, 1 to 2 beats per 150,000 average, or 2/100,000.

4. Tuning of H_2 on a harmonic of H_1. Approximate error, 10 to 20 beats per 500,000 to 1,000,000, or an average of 3/100,000.

(*c*) That which arises in adjusting the wavemeter to the standardised wave.

Effect on wavemeter being standardised :

1. Accuracy of resonance reading. Let us suppose that we find the resonance point by means of two readings of equal amplitude on either side of the resonance curve (see Fig. 8).

We know for this position we have :—

$$\delta \frac{\pi}{2} \frac{f_1 - f_2}{f_0}$$

determining the comparative width of resonance curve.

Now $\delta = 0.016$

whence $\dfrac{f_1 - f_2}{f_0} = 0.01$ approx.

As this width may be appreciable at about 1/75, thanks to the steepness of the two sides of the curve, this gives us an error of appreciation lower than

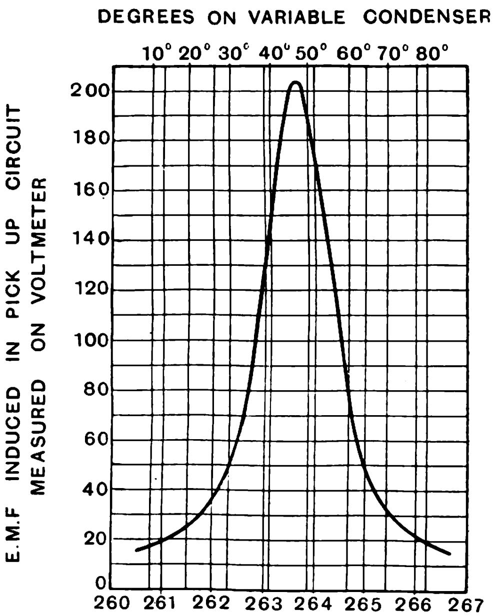


Fig. 8.

1.5/10,000 (as is shown by Fig. 8, representing the resonance curve of wavemeter considered above).

2. The error in reading the graduated scale may be valued at 0.8 of a degree, *i.e.*, at an average of 0.8/10,000.

(*d*) Lastly, that which may arise from an accidental modification of the geometrical dimensions of instruments.

Care has been taken never to deliver an instrument which has not been standardised twice by two different observations, at several days' interval, so as to eliminate systematic errors of observation, as well as those which may arise from the fact that different parts of the instrument may not have yet acquired their state of molecular

equilibrium owing to various processes carried out. As to ulterior modifications, they do not appear to be appreciable according to tests carried out up to the present.

For instance, we may quote the case of the wavemeter of Radio Belgique Station. After having timed the station by means of this instrument, we brought the instrument to our laboratory and completely dismantled it, including the condenser. This was later re-assembled and re-standardised, when it was found that the new standardised curve coincided practically with the first.

To recapitulate the various causes of error, we find that the *error limit* of standardisation is—

$$\frac{1\ (10+2+1+15+8)}{100,000}$$

or about

$$\frac{4}{10,000}$$

As to the *probable error*, it is

$$\frac{1}{100,000}\sqrt{10^2+2^2+1^2+3^2+15^2+8^2}$$

or about

$$\frac{2}{10,000}$$

Now, as each standardisation curve is formed by half-a-dozen points, we may admit that it is exact down to less than about

$$\frac{2}{10,000}$$

As to the order of accuracy of measurements which we may expect of this wavemeter, it evidently depends on the indicator used.

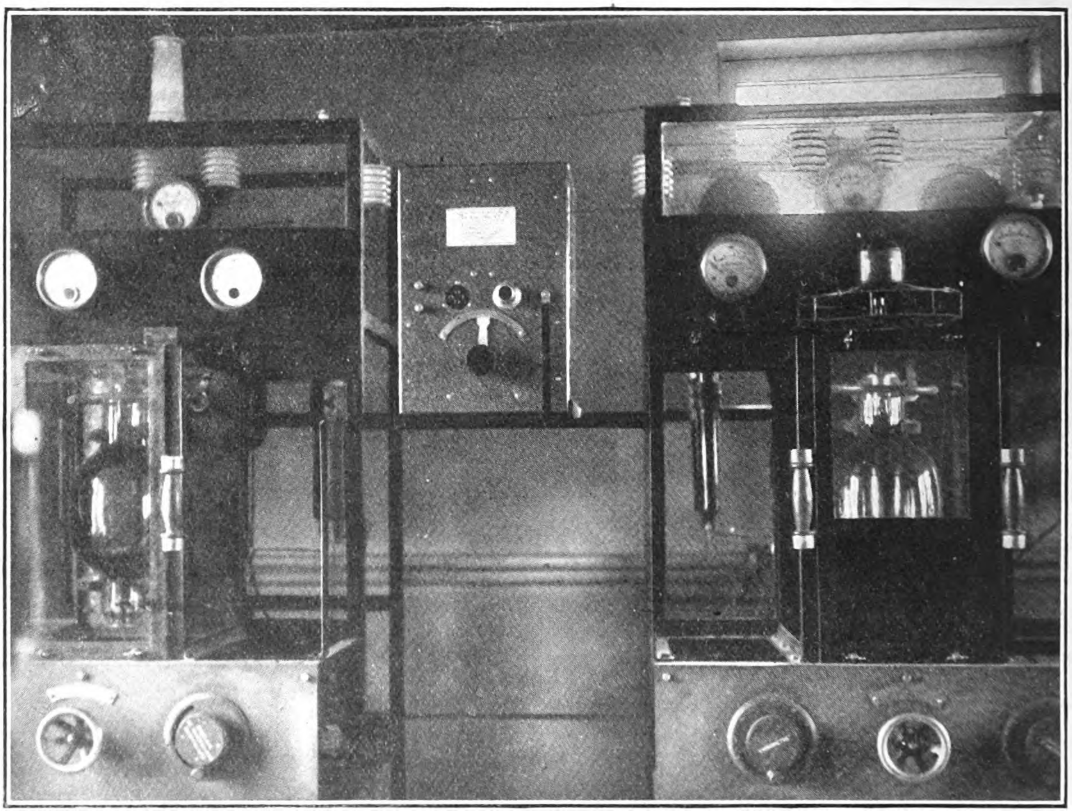


Fig. 9. *Showing the standard wavemeter installed in the Radio-Belgique station at Brussels.*

If this is a thermocouple with a millivoltmeter, an experienced observer can get an accuracy of 1.5/10,000, as we have shown above; if it is an incandescent or glow lamp, the accuracy is not more than 2 to 3/10,000, according to the operator's ability, and according to the degree of incandescence of filament.

Influence of Surrounding Atmosphere.

It is possible to assess theoretically the modification of standardisation involved due to temperature variation.

As far as the condenser is concerned, we can easily see that its capacity depends directly on the coefficient of linear expansion of the aluminium, or a variant of 2.3/100,000 per degree C.

As for inductance, we must first of all consider that the coefficient of expansion of copper (1.9/100,000) neighbours on that of aluminium, so that the sections of the coil forming the facets of the hexagonal prism will expand about the same amount as the aluminium stars forming the bases, and consequently the surface of the coil will grow but not show any deformation.

The wavelength of the circuit varies therefore as

$$\left(1 + \frac{2}{100,000}\right)^{\frac{3}{2}}$$

The result of this is a variation of 3/100,000 approximate per degree C., which it is easy to allow for on standardisation curves.

We have started a series of systematic experimental researches intended to verify our mathematical accuracy. Nevertheless, as these tests are very critical, owing to the accuracy of measurements to be carried out, and also the presence of numerous causes of error, we have not yet obtained results which are sufficiently trustworthy.

Stray Electrostatic and other Effects.

The wavemeter is remarkably well shielded from stray effects depending on the presence of the observer, due to the careful lay-out, in which the various components are mounted on a metal panel which is connected to earth, and to the condenser, of which the outer electrode forms a screen. This encloses the moving plate as well as the dielectric.

Investigations carried out to study the effects of the observer's movements, and particularly his passage between the wavemeter and the transmitting circuit, have shown us that the variations at resonance point resultant therefrom do not arise, as one was tempted to suppose, from a modification of the standardisation of the instrument by the stray effect of capacity, but really from *the modification of the transmitted wavelength*, due to the presence of the body of the observer.

This effect is even appreciable in stations with a power of 1,500 watts to the oscillators.

Conclusions.

We think we have shown by this paper that the problem of the exact and accurate measurement of wavelengths of broadcasting stations may be solved in an industrial manner by the aid of simple and handy instruments.

Fig. 9 shows the installation of the wavemeter above described in Radio Belgique Station, Brussels. It is fitted close to the independent oscillator circuit which fixes the wavelength (drive circuit).

It is extremely easy for technical experts on duty to correct the wavelength transmitted by adjusting the variometer of this circuit, and by observing the glow of the diminutive glow lamp on the wavemeter.

Accurate daily measurements taken at a distance on nearly all of the European stations controlled by such wavemeters, show that the constancy of wavelength transmitted may be easily maintained at about 3 to 4/10,000, no matter how few operators pay attention thereto, and that stations afford the requisite technical qualities, as to stability and accuracy of wavelength adjustment (independent oscillating circuits, variometers, etc.).

There is no doubt that such solutions will soon be imposed in all branches of radio-electrical applications, by reason of the incessant multiplication of transmitting stations.

Design and Construction of a Superheterodyne Receiver.

By P. K. Turner, A.M.I.E.E.

(*Concluded from page* 348 *of June issue.*)

COMING next to the stage comprising the I.F. output and the detector, there is rather more to say. Fig. 24 shows the simplest possible form of this. The first point to be realised here is that the I.F. transformer must be different from the others. They have had, as a secondary load, the grid-filament circuit of a biased valve, of an impedance (at 3,000 metres) probably somewhere between 0.1 and 0.5 megohm. This one is loaded with a crystal which, if galena is used as in this case, is probably in the neighbourhood of 10,000 ohms. Conditions of efficiency obviously dictate a smaller secondary. Theoretically, this secondary should be to the others as the *square root* of its load is to theirs—say about one-fourth. But the matter is slightly complicated by the question of reaction.

It was desired to include reaction over the intermediate amplifier, and one's first instinct was to arrange the circuit as in Fig. 25. But reflection indicated that this was

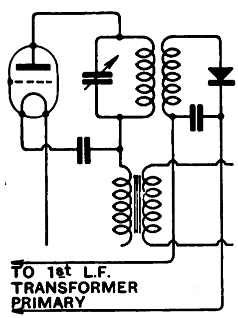


Fig. 24. *If no I.F. reaction is to be used, this circuit is correct for the 2nd detector.*

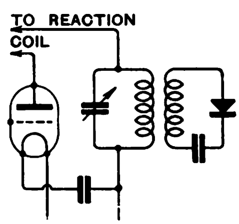


Fig. 25. *An obvious reaction circuit, but not likely to be successful.*

not likely to work well. The transformer is tuned to the working frequency, and therefore, it, with its tuning condenser, will behave as a rejector. That is to say, that it will offer a very high resistance to this frequency; hence the I.F. current in the anode circuit as a whole is very small, although there will be comparatively large I.F. currents circulating round between the primary itself and its condenser. But the reaction coil of Fig. 25 is not within this "circulating circuit," so it will only have a minute I.F. current, and hence will not be very effective.

An alternative is that shown in Fig. 26, in which the reaction coil *is* included with

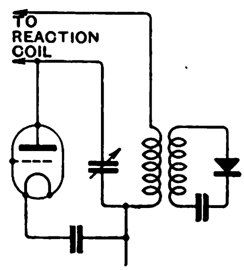


Fig. 26. *This is a more satisfactory reaction arrangement than that of Fig. 25, but it is still by no means the best.*

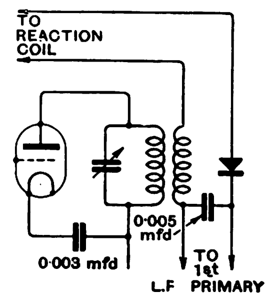


Fig. 27. *Here we have the reaction circuit finally adopted, which proved very satisfactory.*

the transformer primary within the scope of the tuning condenser. It must, of course, be remembered that in this set it is proposed to operate all the condensers by a mechanical connection, so that the effective inductance across each must be the same. Now the effective inductance of the transformer primary depends on its load. If we leave the secondary rather too large, so that the crystal acts as a bigger load, comparatively, than the valves in the case of the other transformers, the effective inductance of the primary will be less, so that the condenser will still tune, even with the extra inductance of the reaction coil.

But we are still in a difficulty, for any change in the reaction coil will upset the tuning, and it is practically impossible to say, before completing the set, what coil is required, so that we want to be free to change it if necessary.

To meet these conditions, we tried, as a new experiment, the circuit of Fig. 27, which has been a complete success. The transformer secondary was re-wound to one-half its former turns, which means that any coil used for reaction only affects the tuning one-quarter as much as it would if used as in Fig. 26. It might be thought that the current in the crystal circuit would be too small to give effective reaction with a reasonable coil, but—at any rate with a galena detector—this is not the case. Quite a small coil (of the order of 50 turns) is needed, and the effect on tuning of a change in the coil seems quite negligible.

As to the detector itself, I never had any intention of using anything else but galena. This hinges on the fact that *with the right holder, or detector,* from the mechanical point of view, galena is perfectly stable and simple to handle, while its efficiency as a transformer of energy is on the average higher than that of the other types that I have measured. Many of the various brands of galena on the market average over 50 per cent. efficiency, occasional samples ranging up to over 90 per cent., while other crystals seldom, in my own experience, average above 30 to 40 per cent., these percentages being input power to actual useful power in the output transformer.

Further, galena has two useful characteristics in connection with distortion. First, its characteristic is very often practically straight above the bend, which, as shown by Colebrook,* is a necessary condition for distortionless rectification of telephony. Second, it has a low apparent output resistance. This means that the output impedance of the transformer primary is likely to be much larger than the output impedance of the crystal at all working audio-frequencies, which in turn, means greater freedom from distortion in this transformer.

I have set in italics a few words above on the matter of the "holder" or detector in which the crystal is arranged. It is bad mechanical arrangement here that is the cause of just about one-half of the present neglect of crystal rectifiers—the other half is due to the fact that so few people seem to have realised that the proper place for crystals is after one or more H.F. valves. The detectors I use take about 1½ in. square on the panel, and project about the same distance. There are two on the set, and they have done the following "records":—

Shepherds Bush to Golder's Green by taxi: Needed *no* adjustment on arrival.

London-Halifax by train, taxi each end: One perfect, the other fair, improved by using a new point.

London-Leicester, train and taxi: One perfect, the other shaken out of contact.

In ordinary domestic use, I usually adjust then about once in six weeks, when I give the set a clean-up all round; they have only *needed* adjustment about three times.

These detectors are on the market at quite a reasonable price (needless to say, I have nothing to do with them except as a satisfied user); they are known as the "Eccentro." As will be seen in the final wiring diagram, two are used, with a switch, to guard against the remote possibility of having one go off during a programme, and to give a check by trying either one if the signals are weak and one suspects the crystal.

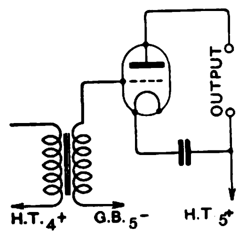


Fig. 28. *As a matter of form, the power valve circuit is given, although it is of standard type.*

The by-pass condenser across the L.F. transformer primary is important. It has a large effect on the input resistance of the detector. Also, it is intended to keep the I.F. component of the rectified current out of the transformer primary, whence (as already explained) it may be transferred back to an earlier valve, leading to uncontrolled reaction. As will be noted shortly, the primary of this transformer is comparatively small, hence an extra effort is made to keep down the reactance of the by-pass condenser by increasing its capacity from the 0.003 used in the other anode

* F. M. Colebrook, "The Rectifying Detector," *E.W. & W.E.*, March, 1925.

circuits to 0.005. This is permissible from the L.F. point of view, for the same reason that the transformer primary is of comparatively low inductance.

As to the transformer, the reason for the small primary suggested above is the obvious one that it is working in a circuit (the crystal) of a few hundred ohms output as the 1 : 8 is on the market as a standard article it was adopted on this set.

Now the output from this transformer, as will be seen from Fig. 23, goes back to a valve of which we have already considered the I.F. operation. It is hardly necessary to give new illustrations showing the L.F. side of these valves, for the essentials are

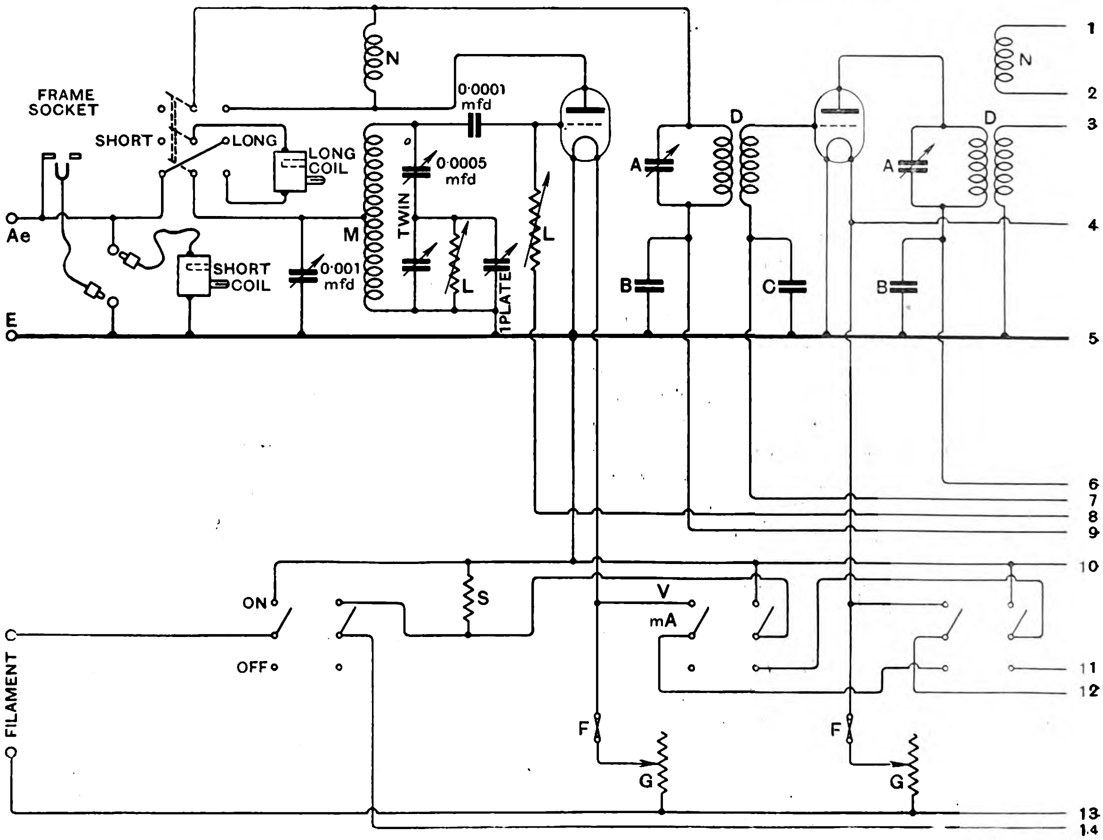


Fig. 29. *The complete schematic diagram. In order to make this fairly easy to read, it has been increased in size. Note that the numbers given to each wire at the break correspond with one another. The values of components are given in some cases in the drawing, the remainder are as follows:* A, .0003μF *max.:*

impedance, as compared with the ten thousand or so of an average valve.

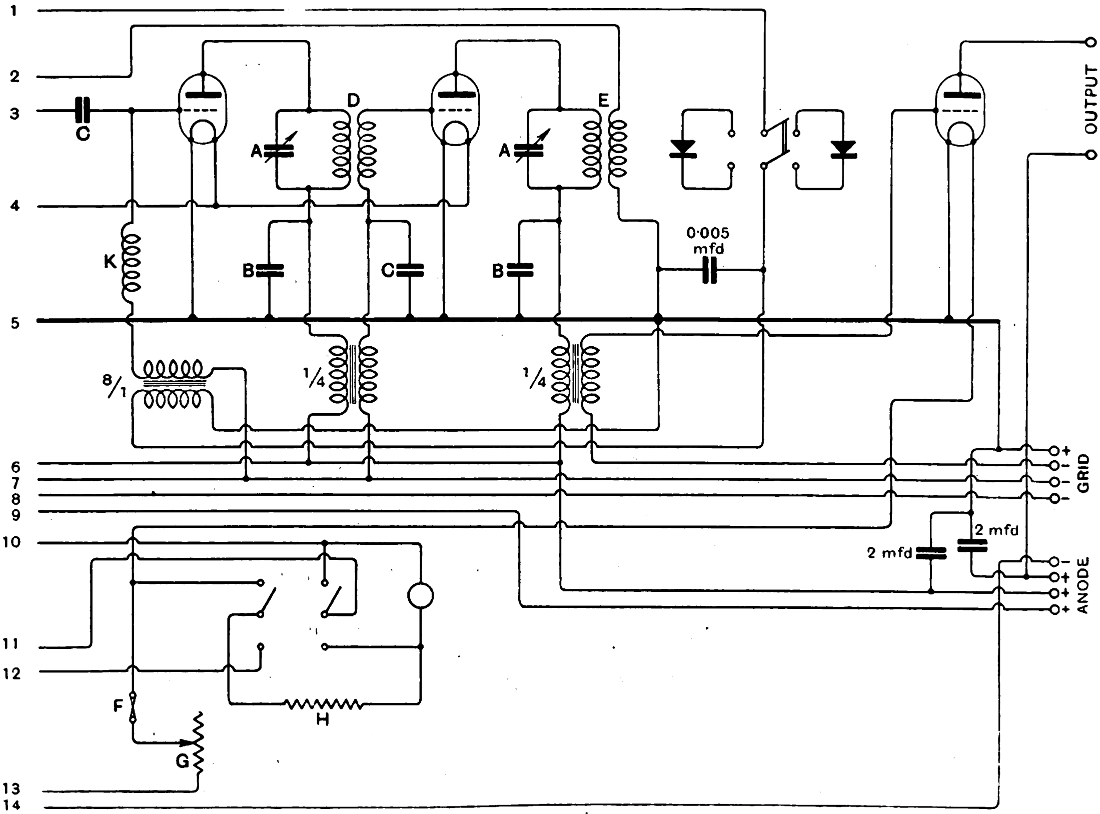
If, as is normally the case, a 1 : 4 transformer is successful with a valve of such anode impedance, which is about 25 times that of a galena crystal, we should think at first of a 1 : 20 transformer after a crystal. But in actual fact the primary of the 1 : 4 transformer is almost always really too small for its job, so we do not make such a large jump. In actual practice a 1 : 8 or 1 : 10 transformer is very satisfactory, and shown in Fig. 23. The two L.F. transformers between valves were selected as 1 : 4 ratio, this being the largest ratio likely to give reasonable absence of distortion with valves of fairly high μ. All three I.F. valves have the H.T.+ leads connected together, also the G.B.—. In use, the grid bias is 1½ to 3, and the H.T. 90 to 120, depending on the valves in use.

It will be remembered that the bottom end of the primary of each I.F. transformer is connected to filament *via* a 0.003 by-pass

condenser. Provision is also made to by-pass the H.T. battery for L.F. purposes, by connecting a $2\mu F$ condenser from the H.T.+ to filament — before the branches to the three valves separate. Theoretically, the grid battery should have a similar by-pass; but it was not considered really necessary here, and is not inserted.

Two in parallel are better, or a "500-ohm" type or two of these in series, or even a "200-ohm" or "low resistance" or two of these. I myself use a "500-ohm" Kone and a 500-ohm horn loud-speaker in parallel, and find the combination the pleasantest thing I have yet struck.

We are now ready to draw a complete



B. $.002\mu F$; C. $.0002\mu F$; D. *McMichael air-core, No. 3;* E. *As "D." but secondary rewound to ½ turns;* F. *Burndept fixed resistor in holder;* G. *Filament rheostat;* H. *Series resistor for meter;* K. 1,800 *or* 1,500 *coil of low self-capacity;* L. *Variable leak,* 1–5*MO;* M. *McMichael "Autodyne" unit;* N. *McMichael reactor.*

Finally, there is the circuit of the power valve. The primary of its transformer is shown in the anode circuit of Fig. 24, and for the sake of completeness the valve circuit is shown in Fig. 28, though it is so simple that this is hardly needed. There are only two points to mention. First, there is another $2\mu F$ condenser to by-pass the H.T. battery. Second, with the normal modern power valve of 4,000 to 10,000 ohms anode impedance the usual type of "2,000 ohm" loud speaker is too high in impedance.

schematic diagram of the set, and this is shown in Fig. 29, complete with switchgear. The values of some of the components are marked; those that are repeated several times are given key letters, and the values are given beneath the diagram.

We have now arrived at the time when the actual layout must be considered. There are one or two points about the set which make this rather tricky. My own preference is for the tuning adjustments to be on a vertical front panel, with the

non-adjustable components on a baseboard. Obviously one must be able to get to the inside of the set to change coils or replace valves. In this instance it was also necessary to have the I.F. transformers accessible; partly because they are interchangeable, but also because the I.F. reaction and the oscillator coupling are controlled by reactors sliding into the transformers.

Another point was that it was desired to have a front lid which would completely enclose the set, while, at the same time, I do not myself like tuning on a sunk panel. This seemed to indicate a deep front lid, which would again be expensive and cumbrous. So it was decided to make the case deeper than the set, and to arrange the base and front to slide right in when the set was to be shut up, or to come forward flush with the front of the case for operation.

Obviously the front panel had to carry

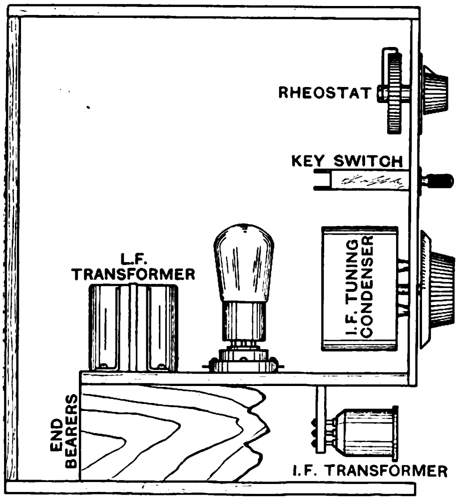


Fig. 30. *The arrangement of the intermediate stages. All these components are centred on the same line.*

the switches, rheostats, keys, meter, detectors, and condensers. It was decided to put the connections on the ends of the cabinet: they are in the way on the front, and (in my opinion) too inaccessible on the back. After much thought, concerned with getting the transformers accessible but not projecting, and at the same time keeping I.F. wiring short, it was decided to adopt for the repeated stages the scheme shown in Fig. 30. The panel is some inches less in height than the case, and the "base-board" is above the floor, the I.F. transformers being below it. The whole rests on two end bearers, which could be either fixed to the base-board (making it like Fig. 31 from the front) or in the form of runners within the case. We finally adopted the former alternative, as we wished the

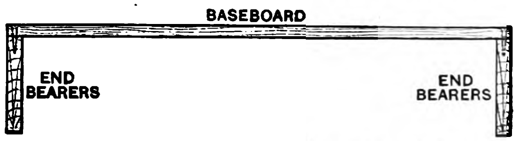


Fig. 31. *How the baseboard is supported clear of the cabinet.*

case to be fairly light and therefore not (if it could be avoided) to have to carry the weight of the "innards" except directly through the bottom.

Having got thus far, we started the pleasing pastime of trying to arrange everything to save space without crowding. We decided that all large components appertaining to one stage should be fixed on one centre-line, so as to allow of the insertion of screens between stages; and so the fullest equipment, that of valves Nos. 2, 3, and 4, became as in Fig. 30. Beyond this, on the right of the set as viewed from the front, is the power valve (L.F. only) and, on the panel, the two crystal detectors and their switch. To the left of the second valve is a stage with no L.F. transformer, but otherwise similar; and to the left of the first valve the aerial and oscillator equipment. Screens are inserted between valves 1-2, 2-3, and 3-4.

The location of most of the accessories can be seen in Fig. 32, which is a diagrammatic plan view, and is numbered for reference: 1 is a socket terminal strip, for aerial and earth (or frame) and L.T.+ and —. The plugs which enter these sockets are on flex leads about 18 inches long, terminating in duplicate Clix which fit in the cabinet: the complete connection from an external wire through the cabinet is as shown in Fig. 33. In this way there it is possible to slide the base-board right in for travel or flush with the front for operation, or even just out of the cabinet for examination, without affecting the connections.

Further, one can if desired disconnect at *A* and *B*, remove the set completely, and connect *C* direct to *D* for test operation away from the cabinet.

2 is the meter, 3 the main switch, 4 and 5 the balancing condenser and resistance for the bridge circuit, 6 the .001 condenser, 7 the twin condenser; 8 and the similar rectangles beside the valve-holders are the fixed H.F. by-pass condensers; 9 is the leak for the first detector, 10 the grid battery. 11 and three similar rectangles are the I.F. tuning condensers; 12 is the long-short switch, and 13 the loading coil socket. 14 are the screens; 15 are the L.F. transformers; 16 the meter keys; and 17 the rheostats.

In the last compartment, 18 are the two H.T. by-pass condensers, 20 the switch for the detector, 21 the detectors, and 22 the H.T.—, two H.T.+, and the output, which are on a strip similar to 1. The I.F. transformers and the autodyne unit are under the baseboard, in the positions indicated by the letters *M D D D E* shown under the sketch.

Fig. 34 shows the front panel, again in diagrammatic form. On the left are the main switch and meter. Next come the aerial and oscillator condensers, and below them the oscillator coil unit with reactor. The square object next at the top of the panel is a calibration chart: under it are the long-short switch, the first I.F. condenser (which controls all four) and the first I.F. transformer: above (not shown) is the socket for the frame aerial. There are now three similar divisions, each containing rheostat, meter switch, and I.F. transformer, one of the latter having a reactor. (The flex leads from the reactors go to Clix in the baseboard.) Lastly, there are the two second detectors with their switch. The "valve" sockets for the I.F. transformers are of course of the "behind panel" type, as in Fig. 35.

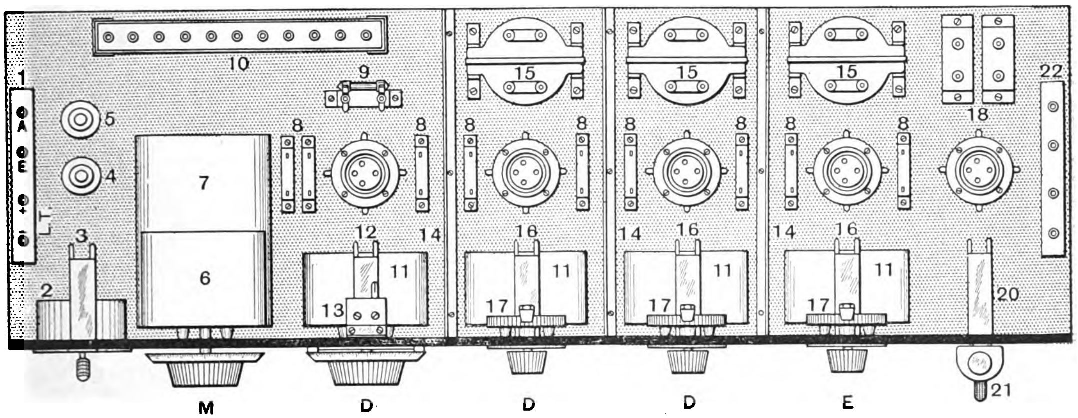


Fig. 32. *The whole layout as far as it can be seen from above. The key to the reference numbers is in the accompanying description.*

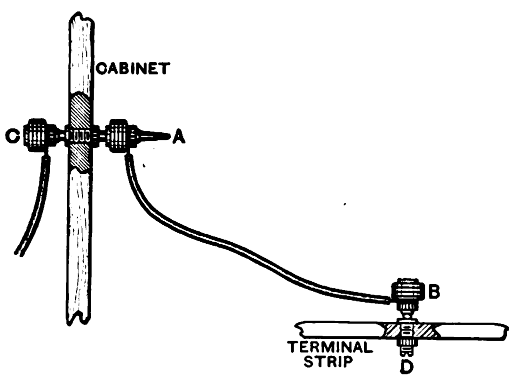


Fig. 33. *All the outside connections are made to the cabinet, and short flex leads go thence to the baseboard.*

One or two constructional points are to be mentioned, as they may be useful to others building similar sets.

The "ganging" of the four condensers was simple. Four pulleys were made in $\frac{1}{8}$ in. ebonite, as in Fig. 36. They were of 2 in. diameter, with brass bushes to fit the

condenser spindles. When the condensers were in place a double-length of mandoline-string (high tensile steel wire, about 34 S.W.G.) was given a complete turn round each, and the ends brought to a miniature the grub-screws and adjust each condenser independently. Two points are important: The pulleys *must* be well made, or there will be tight and loose spots; and the wire joint must be so placed that it only goes from

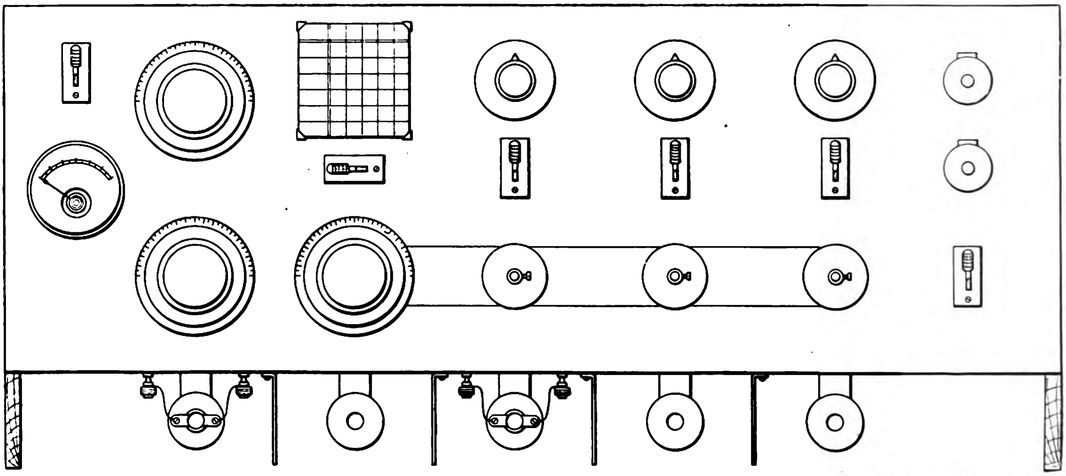


Fig. 34. *From the front we have access to all adjustments, including the reactors. See the neighbouring reading matter to identify the various controls.*

turnbuckle, as used for model aeroplanes, etc., the wire being arranged as in Fig. 37. The left-hand condenser had to receive a knob as well, and its spindle was too short. This was extended by a half-jointed piece made of brass rod, with hack-saw and file, and soldered. In spite of being rather a beginner's job, it worked quite well. When the whole was assembled, it behaved most admirably—no slip nor backlash, but quite smoothly; it is also quite easy to slack

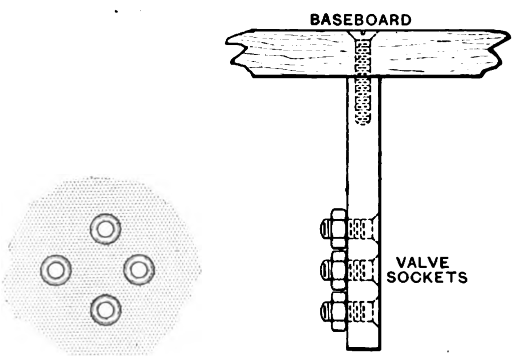


Fig. 35. *Sockets for the transformers.*

A to *B* (Fig. 37) during the whole movement: it naturally won't go round the pulleys.

The frame aerial used with this set was enclosed in the removable front of the box. As already stated, the whole set was made to slide within the cabinet, so that a front

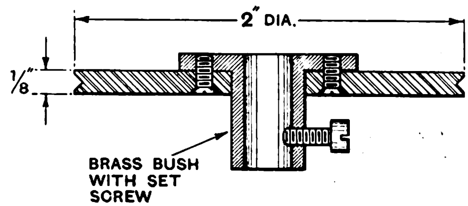


Fig. 36. *To enable all the I.F. condensers to be worked from one control, they were fitted with these pulleys.*

lid could be put on to enclose it completely when slid back, but allowing the front panel to come forward flush with the box for operation. This was worked as shown in Fig. 38; the two runners below the ends of the baseboard were fitted with bolts (common household variety) which dropped into holes in the bottom of the cabinet.

Two pairs of holes were provided to give the two positions.

The fittings of the front lid itself comprised (*a*) two pegs on the lower edge, engaging with holes inside the lower front edge of the cabinet. The pegs were short, and the holes loose enough to let the lid tilt back so that it could be lifted clear. (*b*) Two ball catches

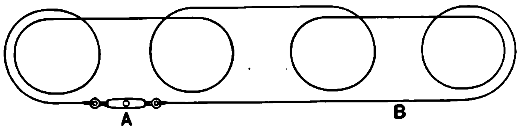


Fig. 37. *Round the pulleys of* Fig. 36 *goes a fine steel wire, linking all together.*

let into the upper edge, engaging in holes within the upper edge of the cabinet. (*c*) A lock engaging with a socket on the upper edge of the cabinet.

Besides these fittings, enabling it to act as a lid, the lid was also fitted as a frame aerial. Its general construction is shown in Fig. 39. A sheet of mahogany veneer 3-ply was fitted with three strips of mahogany, $\frac{3}{4}$ in. wide and $\frac{1}{2}$ in. thick, round three of its edges, the fourth having a strip 2 in. wide; and also with four ebonite combs 4 in. long by $\frac{1}{2}$ in. thick by $\frac{5}{8}$ in. wide. One of the combs is shown separately in the circle, which shows how the slots in it were undercut to prevent the wires slipping out, and were

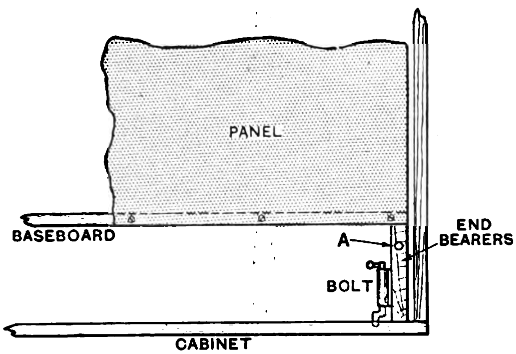


Fig. 38. *Bolts lock the baseboard in either the working or travelling position. A is the carrying socket for the frame aerial spindle when the set is closed up.*

slightly deeper than half the thickness of the comb, so that the wire winding comes central in the open space within the lid. After winding the frame, a second sheet of 3-ply was screwed down over the winding, the whole forming a hollow lid.

The frame, when in use as such, rotates on a spindle fitted in the lid of the set, the arrangements for location and contact being shown in Fig. 40. Here the upper sketch shows a section of part of the frame, and the lower the corresponding part of the cabinet

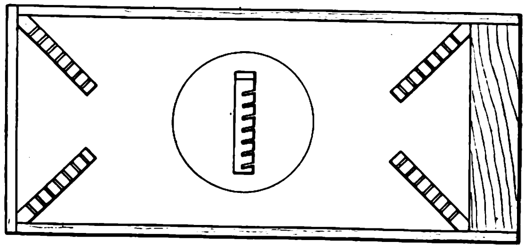


Fig. 39. *The general design of the frame-lid: in the circle, a side view of one of the combs.*

top. *A* is the 2 in. wide mahogany strip forming one end of the hollow lid, *B* being part of the 3-ply cover. *A* is drilled to take *C*, which is a brass tube, $\frac{1}{4}$ in. inside and about $\frac{3}{8}$ in. outside, sweated to an oblong flange $\frac{1}{2}$ in. by 2 in. *C* is made a tight tapping fit in the hole, and when the flange is screwed down is quite secure. The most

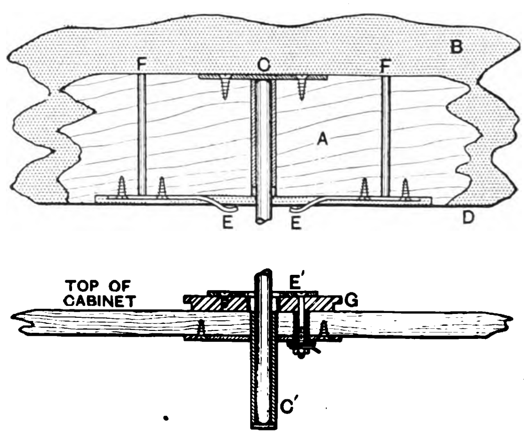


Fig. 40. *Details of the combined spindle and contact arrangements for the frame.* [*The disc* G *is undercut to take the compass card.*

important point is to see that *C* is truly square with the lower edge *D* of the whole frame. *A* is cut away about $\frac{1}{8}$ in. deep on its lower edge for two or three inches each side of *C*, and the two hard brass

springs E affixed. Contact to the two ends of the frame is made by C and E, the leads to E being in parallel (*i.e.* both springs E are one contact). The leads to E go down the holes F.

In the cabinet, a corresponding tube C' is fitted. This, however, has a flange the right distance along it to make its upper end flush with the outside of the cabinet. Its lower end is enclosed by a disc sweated on.

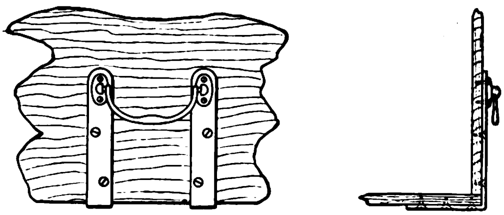


Fig. 41. *A useful tip for transferring lifting stresses in a heavy set with a light cabinet.*

The two springs E of the frame rub on a brass ring E' mounted on an ebonite ring G, the latter being screwed to the cabinet.

The spindle itself is loose, for otherwise it would make an awkward projection when the set is closed up. When the set is to be erected, the spindle—a plain piece of $\frac{1}{4}$ in. brass rod with rounded ends—is dropped into C', and the frame lowered onto its projecting upper end. The length of the spindle and the strength of springs E need a certain care. The strength of E should be such that the frame's own weight just makes them go flush with the edge D, from which they should project about $\frac{1}{8}$ in. when there is no weight on them. Then the length of the spindle should be adjusted so that when it is in contact with the ends of C and C', D is $\frac{1}{16}$ in. above E'. Under these conditions, half the weight of the frame is taken by the springs and half by the spindle, and both will make first-class contact. Connection from E' to the set is made by making one of the screws for E' a long bolt which goes right through a clearing hole in the timber, with an ebonite bush on the inside end. It was originally intended to provide ebonite insulation for springs E, but it was found quite unnccessary.

When the frame is not in use, the loose spindle is housed as shown in Fig. 38. The hole A in the runner is long enough to take all but $\frac{1}{2}$ in. of the spindle, which is a loose push fit therein.

This frame has, for its middle turn, an area of just about 1 ft. by 2 ft., and has 8 turns. It was quite successful, though naturally not so powerful as a larger frame built later on. Nevertheless, it was good enough to get practically everything in Europe of 1kW or over, at good loud-speaker strength.

Going back for a moment to the wiring diagram, Fig. 29, it may be noticed that arrangements are made to put a coil socket (marked "Short Coil") in series or parallel with the frame, or across A and E. This socket, and the four Clix which bring it and the frame into action, are fitted to the *cabinet*, flex leads from the A and E terminals going to the set as already stated.

Other fittings on the cabinet are to make the set easier to carry. A brass drop handle is fitted at each end, and since the set is heavy and the cabinet none too strong, $\frac{1}{16}$ in. brass straps from the handles are taken down under the bottom of the cabinet and screwed there, as shown in Fig. 41.

Lastly, there is the compass-card. This is a disc of thin 3-ply, about 7 in. diameter, with a hole large enough to be a loose fit round the lower part of the ebonite bush G

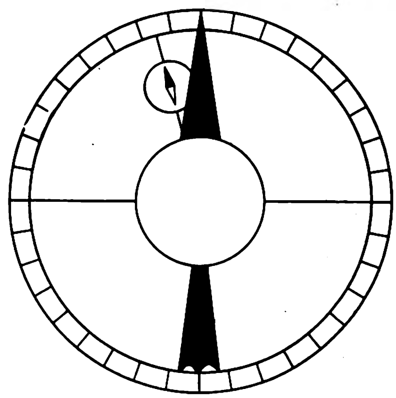


Fig. 42. *For checking bearings: a large compass card, set by means of a small compass and then locked. The actual card is of course marked in degrees.*

(Fig. 40). It is thus held in place, but is free to rotate. It is marked with every 10° of bearing, and has also a line drawn for 345°, corresponding to the Magnetic North. On this line is centred a hole about 1 in. diameter, into which fits a small

pocket compass; there is also, screwed to the cabinet, a locking device like a gramophone brake, to hold the card in position when it has been set with the compass needle lying along its radius.

The Set in Operation.

The set was a success from the first. It was completed and first had the batteries connected up two days before the first all-European broadcast tests in the autumn of 1925. There were the usual minor troubles in getting the adjustments right, but during the six hours of the tests (12 p.m. to 2 a.m. on three successive nights) we averaged 29 stations per night, definitely identified, 10 more per night tentatively identified by direction and wavelength, and 8 more unidentified—not bad for a brand-new set.

Trials were made on an outdoor aerial—quite justified, since radiation is negligible on account of the bridge circuit. Generally speaking the results gave little increase in *effective* power over the frame. Signals were, of course, more powerful, but even with the frame the limiting range of reception was simply that at which interference became excessive.

On the frame (which was almost always used) it was noticeable that the oscillator tuning was very sharp indeed, while the frame tuning was not very sharp. So sharp was the oscillator that we found tuning quite tricky at the short end of the scale even with an 80 : 1 geared dial; one could get and lose a distant station in the thickness of a degree line! As to effective selectivity: at the end of 1925 we were located just two miles west of 2LO, and at that time Manchester and Cardiff were more or less equally spaced each side of 2LO's wave.

Manchester could be easily got, because the frame helped. But for Cardiff, the frame had to be right for London at the same time, the set being dead on the line between the two stations; and the best we could do was to reduce London to the same strength as Cardiff.

As we got used to handling the set, it soon became obvious that the strength was usually excessive. We placed a Bretwood variable anode resistance across the primary of one of the L.F. transformers, with good results; but finding that it was almost always reduced to about 5,000 ohms or less, we eventually cut one L.F. stage right out, reflexing to the fourth valve (see Fig. 29) instead of the third. This rather improved the tone, as one could use more I.F. amplification and so get a greater input to the detector before the strength got too great at the loud-speaker.

The set remained in this condition, giving complete satisfaction, until the end of 1926, when it was decided to do some more experimental work. It has since been altered in various ways—perhaps in a few months' time it will reach a stable condition again!

Now as to suggestions for improvement. As we have already hinted, the use of a variable intermediate frequency was not entirely successful, owing to instability when the condensers are reduced. The obvious cure for this is neutralisation, but this means a change in the I.F. transformers, the McMichael ones originally used not being suited to this in their purchased form.

As regards the detector-oscillator circuit, this was completely successful; but there are some interesting methods known now in which the circuits are made simpler by using a tetrode instead of a triode.

In view of the improvement in loud-speakers since the set was made, the L.F. end can no longer be considered good enough for one of fastidious taste. The first transformer, between crystal and valve, may be considered to give negligible distortion, but it would probably be best to use resistance coupling between the reflexed valve (only one now, not two as in Fig. 29) and the power valve.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page 354 of June issue.*)

12. An Important Geometrical Proposition (the Pons Asinorum).

As a matter of fact we have already crossed this bridge (the reader must excuse the imputation) in the preceding section, but its very important geometrical significance must be made more clear.

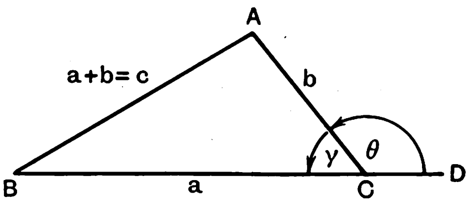


Fig. 24.

The vectors $\mathbf{c}=\mathbf{a}+\mathbf{b}$, $\mathbf{a}$, and $\mathbf{b}$ form a triangle as shown in Fig. 24.

From Section 11,

$$\mathbf{c}^2=(\mathbf{a}+\mathbf{b})^2=\mathbf{a}^2+\mathbf{b}^2+2\,\mathbf{a}\cdot\mathbf{b}$$

Putting in the scalar magnitudes of these scalar products and squares,

$$c^2=a^2+b^2+2ab\cos\theta$$
$$=a^2+b^2-2ab\cos\gamma$$

since $\theta+\gamma=\pi$ (180°).

Applications and Deductions.

(*a*) Given two sides of a triangle (*a* and *b*) and the angle between them the magnitude of the third side can be calculated from the formula

$$c^2=a^2+b^2-2ab\cos\gamma$$

(*b*) Given the three sides of a triangle, *a*, *b*, and *c*, the angle γ between *a* and *b* is given by

$$\cos\gamma=(c^2-a^2-b^2)/2ab$$

which, together with the fact that γ must be less than 180° defines γ completely.

It follows from this that if two triangles are equal as to the lengths of their sides they are equal in every respect. (See Section 5, Part II).

(*c*) The special case known as the Pons Asinorum (*Euclid* I, 47)

If $A\hat{C}B$ is a right angle (Fig. 25) then

$$\cos\gamma=0$$

and $$c^2=a^2+b^2$$

Thus, in a right-angled triangle, the square on the hypotheneuse is equal to the sum of the squares on the other two sides.

This leads to the functional relationship between the trigonometrical ratios of an angle to which a reference was made in anticipation in Section 7. Since (Fig. 25)

$$a^2+b^2=c^2$$
$$(a^2/c^2)+(b^2/c^2)=1$$

or $$(a/c)^2+(b/c)^2=1$$

i.e., $$(\cos\beta)^2+(\sin\beta)^2=1$$

or, as it is usually written,

$$\cos^2\beta+\sin^2\beta=1$$

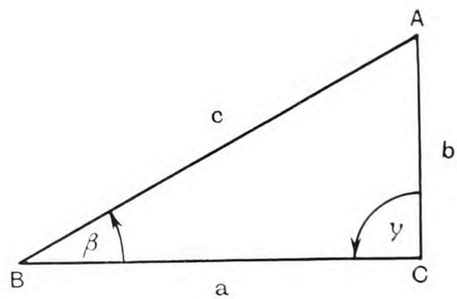


Fig. 25.

This relationship can of course be expressed in a variety of ways. For instance division by $\cos^2\beta$ gives

$$1+\tan^2\beta=\sec^2\beta$$

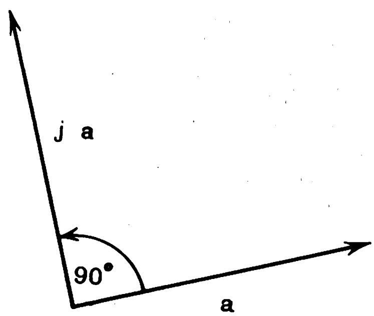
and so on.

13. The Operator "j".

This introduces a somewhat controversial topic. The symbol "j" is very widely employed in alternating current analysis, but there is a divergence of opinion as to

its essential character and occasionally discussions arise as to the legitimacy of certain applications of it or as to the interpretation of expressions in which it appears.

Of course any system of ideas which, to put it colloquially, "delivers the goods" and which is self-consistent, can be used as the basis of a system of symbolic logic. The operator interpretation here described is not put forward as the inspired word and only



Fig, 26.

true gospel. All that is claimed for it is that it is clear and self-consistent and avoids some of the difficulties of interpretation associated with the imaginary quantity and complex number nomenclature.

Two types of operator with a vector operand have already been introduced. The first is simple scalar multiplication represented by the a in $a\mathbf{a}_1$, which increases the length of its operand without altering its direction. The second is the operator -1 which reverses the direction of its operand without changing its magnitude. A third will now be introduced. The operator j rotates its vector operand through $\pi/2$ (90°) in a positive direction in a given plane without changing its magnitude. The vectors $\mathbf{a}$ and $j\mathbf{a}$ will therefore be as shown in Fig. 26. (The plane of the operation will be taken throughout as the plane of the paper.)

It follows from the definition of j that

$$j(j\mathbf{a}) = -\mathbf{a}$$

For shortness $j(j\mathbf{a})$ can be written $jj\mathbf{a}$ and still more compactly as $j^2\mathbf{a}$ but the real significance of j^2 should be borne in mind. Then

$$j^2(\ ) = -1(\ )$$

Similarly $\quad j^3 = -j$

and $\quad j^4 = 1$

so that the relationship between "powers" of j and j and 1 is the same as that between powers of $\sqrt{-1}$ and $\sqrt{-1}$ and 1. Whether or no this establishes any identity between j and $\sqrt{-1}$ is irrelevant to the present purpose. The important point is the effect of powers of j, *i.e.*, of successive operations with j.

The operator j can obviously be combined with a scalar number or multiplier and the association is commutative, for $aj\nu$ is the same vector as $ja\nu$, from which it follows that the operator aj is the same in effect as ja.

14. (*a*) The Operator $(a+jb)$.

The obvious interpretation of $(a+jb)\nu$ is $a\nu+jb\nu$. This is illustrated in Fig. 27. Notice that

$$(a+jb)\nu = (jb+a)\nu$$

by elementary geometry. In the above a and b can be any positive or negative numbers or fractions.

It follows from para. (*c*) of Section 12 that (Fig. 27)

$$BA^2 = BC^2 + CA^2$$

i.e., writing r for the magnitude of BA,

$$r^2 = a^2 + b^2$$

or $$r = +\sqrt{a^2+b^2}$$

while θ is defined by

$$\sin\theta = b/r \quad \cos\theta = a/r \quad \tan\theta = b/a$$

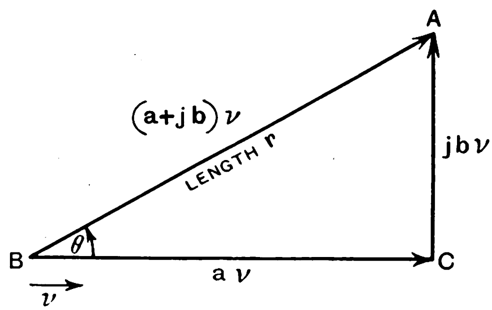


Fig. 27.

which make θ quite definite for given signs and magnitudes of a and b. The effect of the operator $(a+jb)$ is thus seen to be a rotation through θ specified as above, combined with a multiplication by $r=\sqrt{a^2+b^2}$, and this effect is quite independent of the actual operand, which may be a unit vector as in Fig. 27, or any other vector whatever. Further by a suitable choice of a and b, r and

θ can be made to assume any values whatever and any vector in the plane of the operation can be represented in the form $(a+jb)\nu$. The operator $(a+jb)$ can therefore be regarded as the most general possible form of co-efficient in any given plane. Its importance for students of electricity lies in the fact (to be demonstrated later) that any alternating current impedance can be expressed in this form. The fairly detailed study of this co-efficient and its combinations is therefore a practical necessity. The calculus of such co-efficients will prove to be identical in form with that of complex numbers, but its full geometrical significance will probably be missed if this is simply taken for granted.

The effect of the operator can be specified exactly in terms of a scalar product. If the vector $\mathbf{u}$ is of length u and direction ψ with respect to ν, then

$$\mathbf{u}\cdot\nu = u \cos\psi$$

and from the preceding it follows that

$$(a+jb)\,\mathbf{u}\cdot\nu = ru\cos(\psi+\theta)$$

a result which should be noted carefully because of its later significance in alternating current analysis.

(*b*) Addition of Operators.

By applying the laws of commutation and association in the addition of vectors

$$\begin{aligned}\{(a+jb)+(c+jd)\}\nu &= (a+jb)\nu+(c+jd)\nu\\ &= a\nu+jb\nu+c\nu+jd\nu\\ &= a\nu+c\nu+jb\nu+jd\nu\\ &= (a+c)\nu+(jb+jd)\nu\\ \text{therefore}\quad &= \{(a+c)+j(b+d)\}\nu\end{aligned}$$

The reader is advised to interpret all these steps geometrically. It appears that the addition of operators follows the same rules as that of complex numbers. The result can obviously be extended to the additon (or subtraction) of any number of operators.

(*c*) Equality of Operators.

The equation

$$(a+jb)\nu=(c+jd)\nu$$

clearly implies the operator equality

$$(a+jb)=(c+jd)$$

If to each of the equal vectors in the first equation we add the vector $(-jb-c)\nu$ we get

$$(a-c)\nu=(d-b)\,j\nu$$

i.e., a vector equal to another which is perpendicular to it; but this is impossible by the definition of a vector unless each is zero.

Therefore if $(a+jb)=(c+jd)$

then $a-c=0$ and $d-b=0$

i.e., $a=c$ and $b=d$

This process can be compared with the separate equating of the real and imaginary parts of equal complex numbers. In operators the components can be referred to as the "a" and "b" parts, or, perhaps better as suggested by A. Eagle, of the Victoria University, the "axial" and "non-axial" parts. Neither of these alternatives is quite satisfactory, but either is better than the customary "real" and "imaginary" which are misleading and confusing.

As a special case of the above we have, if

$$a+jb=0$$

then $a=0$ and $b=0$

(*d*) Multiplication of Operators.

By the geometry of similar triangles it is easy to show that

$$\begin{aligned}a\{(c+jd)\nu\} &= a(c\nu+jd\nu)\\ &= ac\nu+ajd\nu\\ &= ac\nu+jad\nu\end{aligned}$$

and similarly

$$b\{(c+jd)\nu\}=bc\nu+jbd\nu$$

and

$$\begin{aligned}jb\{(c+jd)\nu\} &= jbc\nu+jjbd\nu\\ &= jbc\nu-bd\nu\end{aligned}$$

and by addition

$$\begin{aligned}(a+jb)\{(c+jd)\nu\} &= ac\nu+jad\nu+jbc\nu-bd\nu\\ &= \{(ac-bd)+j(ad+bc)\}\nu\end{aligned}$$

The intermediate brackets on the left-hand side can be omitted, though they are required for a comprehensible interpretation. Then

$$(a+jb)\;(c+jd)\nu=\{(ac-bd)+j(ad+bc)\}\nu$$

or considering the operators only

$$(a+jb)\,(c+jd)\;=(ac-bd)+j(ad+bc)$$

which again is similar to the same operation with complex numbers.

The above two results for addition and multiplication can be extended to division, powers, etc., precisely as for the same operations with real or complex numbers described in Part I, and no new rules have to be learnt. The interpretations will be

sufficiently obvious in most cases. For instance the equation

$$\mathbf{u} = \frac{1}{a+jb}\mathbf{v}$$

really means that $\mathbf{u}$ is that vector which, operated on with $(a+jb)$, gives $\mathbf{v}$,

i.e., $$(a+jb)\mathbf{u} = \mathbf{v}$$

Operating on each of these equal vectors with $(a-jb)$ gives

$$(a-jb)\,(a+jb)\,\mathbf{u} = (a^2+b^2)\,\mathbf{u} = (a-jb)\,\mathbf{v}$$

or $$\mathbf{u} = \frac{(a-jb)}{(a^2+b^2)}\mathbf{v}$$

which is the process corresponding to the rationalisation of complex numbers.

The interpretation of roots of operators will require a little more care and will be considered more fully later on.

Before leaving this part of the subject it will be well to point out the distinction between $(a+jb)\,(c+jd)\nu$, which implies successive operations on ν, and $(a+jb)\nu\cdot(c+jd)\nu$, which is the scalar product of two vectors. By applying the results of Section 11 it is easy to show that the latter is simply the number $(ac+bd)$. This latter form will be met later in connection with expressions for the power in alternating current circuits.

15. Alternative Form for $(a+jb)$.

Referring back to Fig. 27,

$$a = r\cos\theta \text{ and } b = r\sin\theta$$

so that $$(a+jb) = r\,(\cos\theta + j\sin\theta)$$

and since the effect of $(a+jb)$ is multiplication by r and rotation through θ in a positive direction it is clear that the operator $(\theta\ \cos\theta + j\sin\theta)$ represents the rotation through θ. (Fig. 28.)

So far θ is inherently a positive number, but this restriction can be removed, for if

$$\mathbf{u} = (\cos\theta + j\sin\theta)\,\mathbf{v}$$

be written in the form

$$\mathbf{v} = \frac{1}{\cos\theta + j\sin\theta}\mathbf{u}$$

it is clear that $1/(\cos\theta + j\sin\theta)$ means a rotation of amount θ in a negative direction, *i.e.*, a rotation $-\theta$. But by the preceding section

$$\frac{1}{\cos\theta+j\sin\theta} = \frac{\cos\theta - j\sin\theta}{\cos^2\theta+\sin^2\theta}$$
$$= \cos\theta - j\sin\theta$$
$$= \cos(-\theta) + j\sin(-\theta)$$

so that $\cos(-\theta)+j\sin(-\theta)$ effects a rotation of $-\theta$. Therefore for positive or negative values of θ, $(\cos\theta+j\sin\theta)$ effects a rotation θ.

Successive rotations of θ_1 and θ_2, these being positive or negative, are obviously equivalent to a single rotation $(\theta_1+\theta_2)$. Therefore $(\cos\theta_1 + j\sin\theta_1)\,(\cos\theta_2 + j\sin\theta_2) = \cos(\theta_1+\theta_2) + j\sin(\theta_1+\theta_2)$

This remarkable formula, which, in its operator interpretation is self-evident, embodies what is known in pure mathematics as

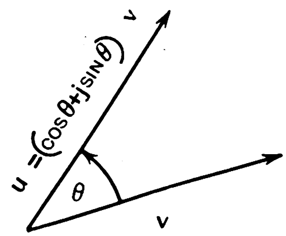


Fig. 28.

De Moivre's Theorem. Many results of far-reaching importance can be deduced from it. Some of these will now be considered.

16. The Addition Formulæ of Trigonometry.

Since

$$\cos(\theta_1+\theta_2) + j\sin(\theta_1+\theta_2)$$
$$= (\cos\theta_1 + j\sin\theta_1)\,(\cos\theta_2 + j\sin\theta_2)$$
$$= \cos\theta_1\cos\theta_2 - \sin\theta_1\sin\theta_2 + j(\sin\theta_1\cos\theta_2 + \cos\theta_1\sin\theta_2)$$

by multiplication, as in Section 14D, then equating separately the a and b parts

$$\cos(\theta_1+\theta_2) = \cos\theta_1\cos\theta_2 - \sin\theta_1\sin\theta_2$$
$$\sin(\theta_1+\theta_2) = \sin\theta_1\cos\theta_2 + \cos\theta_1\sin\theta_2$$

From these two important formulæ many others can be derived as special cases. For instance, if $-\theta_2$ be written for θ_2,

$$(\cos(\theta_1-\theta_2) = \cos\theta_1\cos\theta_2 + \sin\theta_1\sin\theta_2$$
$$\sin(\theta_1-\theta_2) = \sin\theta_1\cos\theta_2 - \cos\theta_1\sin\theta_2$$

and if in the first pair we put $\theta_1 = \theta_2 = \theta$

$$\cos 2\theta = \cos^2\theta - \sin^2\theta$$
$$= 2\cos^2\theta - 1$$
$$= 1 - 2\sin^2\theta$$

(since $\cos^2\theta + \sin^2\theta = 1$) and

$$\sin 2\theta = 2\sin\theta\cos\theta.$$

Similarly formulæ for the tangent and cotangent of sums and differences, and for the ratios of 3θ, 4θ, etc., can be obtained by inserting appropriate special values in the original formulæ. The product formulæ $2 \sin \theta_1 \sin \theta_2 = \cos (\theta_1 - \theta_2) - \cos (\theta_1 + \theta_2)$ etc., etc., should be noted as they have many applications in wireless telegraphy and telephony. However, the only ones that really need be remembered by heart are the formulæ for the sin and cos of $(\theta_1 + \theta_2)$ for the others can be derived from them very simply.

17. The Exponential Form for $(\cos \theta + j \sin \theta)$.

Since n equal rotations of θ are equal to a single rotation $n\theta$, n being a positive integer.

$$\cos n\theta + j \sin n\theta = (\cos \theta + j \sin \theta)^n = \cos^n \theta (1 + j \tan \theta)^n$$

Now put $n\theta = \phi$, then

$$\cos \phi + j \sin \phi = \cos^n \frac{\phi}{n} (1 + j \tan \frac{\phi}{n})^n$$

This formula will remain true however large n may be so that

$$\cos \phi + j \sin \phi = \lim_{n \to \infty} \cos^n \frac{\phi}{n} \left(1 + j \tan \frac{\phi}{n}\right)^n$$

Now by sufficiently increasing n, $\tan \frac{\phi}{n}$ can be made to differ from ϕ/n by as little as we please, and $\cos^n \frac{\phi}{n}$ can be made to differ from 1 by as little as we please. This can easily be appreciated by drawing a diagram showing θ, $\tan \theta$, and $\cos \theta$ for a very small angle θ. Therefore, remembering the definition of "limit" (Section 8 of Part I, January, 1927)

$$\lim_{n \to \infty} \cos^n \frac{\phi}{n} \left(1 + j \tan \frac{\phi}{n}\right)^n = \lim_{n \to \infty} \left(1 + j \frac{\phi}{n}\right)^n$$

It has been shown that the multiplying together of operators follows the same rules as the multiplication of real or complex numbers. Therefore the product $\left(1 + j \frac{\phi}{n}\right)^n$ can be written down by the Binomial Theorem for a + *ve* integral index (Section 10 of Part I) and the limit when n tends to infinity can be found in exactly the same way as is shown in full in Section 11 of Part I. The result is

$$\cos \phi + j \sin \phi = 1 + j\phi + \frac{(j\phi)^2}{2!} + \frac{(j\phi)^3}{3!} \text{ etc., etc., } ad\ inf.$$

The infinite series on the right will be written $S(j\phi)$ for shortness. If x is any real number

$$S(x) = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \text{etc., etc., } ad\ inf. = \varepsilon^x$$

(Section 11, Part I) where ε is the number 2.71828 . . . . But this does not mean that $S(j\phi)$ is similarly $\varepsilon^{j\phi}$, for how can any number be multiplied by itself $j\phi$ times? Nevertheless $\varepsilon^{j\phi}$ will be adopted as a convenient short way of writing $S(j\phi)$ or the operator $(\cos \phi + j \sin \phi)$ which has the same effect, and this practice will not lead to any errors for it has already been shown that

$$(\cos \theta_1 + j \sin \theta_1)(\cos \theta_2 + j \sin \theta_2) = \cos(\theta_1 + \theta_2) + j \sin (\theta_1 + \theta_2)$$

which in the exponential form becomes

$$\varepsilon^{j\theta_1} \varepsilon^{j\theta_2} = \varepsilon^{j(\theta_1 + \theta_2)}$$

which is in formal agreement with the index law. The $j\phi$ in $\varepsilon^{j\phi}$ does actually function as an index as far as combinations of such quantities are concerned, and the exponential form of writing is therefore a convenient and legitimate way of expressing this fact. Remember, however, that the index behaviour is derived first and independently and is not a deduction from the exponential form. On this understanding any operator $(a + jb)$ can be written in the form

$$(a + jb) = r(\cos \theta + j \sin \theta) = r\varepsilon^{j\theta}$$

where r and θ are as specified in Section 14A. The convenience of this last form for calculation will be apparent later on. Remembering the effect of the operator $r\varepsilon^{j\theta}$, it is easy to see that $r\varepsilon^{j\theta}\nu$ is a vector of magnitude r making an angle θ with the direction of ν, so that

$$r\varepsilon^{j\theta}\nu \cdot \nu = r \cos \theta$$

In particular the vector $\hat{e}\,\varepsilon^{j\omega t}\nu$ is of magnitude $\hat{e}$ and makes with ν an angle which increases at the rate ω radians per second (t representing the time in seconds from some definite zero or starting point), *i.e.*, it is a vector of constant magnitude rotating with constant angular velocity, and

$$\hat{e}\varepsilon^{j\omega t}\nu \cdot \nu = \hat{e} \cos \omega t$$

Such an operator can therefore be used to specify an alternating E.M.F. in the vector form $\hat{e}\varepsilon^{j\omega t}\nu$. In practice it will not be necessary to write in the unit vector of reference ν but its implicit existence as the

operand of $\hat{e}\epsilon^{j\omega t}$ should be borne in mind and will generally facilitate the interpretation of vector calculations. The significance of this will appear more fully later on.

18. Series Form for Sine and Cosine.

Another very interesting result is derived from De Moivre's Theorem as follows:—

$$\cos\theta + j\sin\theta$$
$$= 1 + j\theta + \frac{(j\theta)^2}{2!} + \frac{(j\theta)^3}{3!} + \frac{(j\theta)^4}{4!} + \frac{(j\theta)^5}{5!} + \text{etc., etc. } ad\ inf.$$
$$= 1 + j\theta - \frac{\theta^2}{2!} - \frac{j\theta^3}{3!} + \frac{\theta^4}{4!} + \frac{j\theta^5}{5!} + \text{etc., etc. } ad\ inf.$$
$$= \left(1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} + \text{etc., etc.}\right) + j\left(\theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \text{etc., etc.}\right)$$

Therefore equating separately the *a* and *b* parts of these operators

$$\cos\theta = 1 - \frac{\theta^2}{2!} + \frac{\theta^4}{4!} - \text{etc., etc. } ad\ inf.$$
$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \text{etc., etc. } ad\ inf.$$

These series are rapidly convergent for small values of θ and give as convenient approximations for such small values

$$\cos\theta = 1 - \theta^2/2$$
$$\sin\theta = \theta - \theta^3/6$$

19. Roots of Operators.

By analogy with the ordinary arithmetical meaning of "root" the *n*th root of the operator $r(\cos\theta + j\sin\theta)$ will be taken to mean any operator which repeated *n* times, *i.e.*, raised to the *n*th power, has the same effect as $r(\cos\theta + j\sin\theta)$. We shall now see that if *n* is an integer there will be *n* different operators which fulfil this condition. First let $r^{1/n}$ be written for that positive number which, raised to the *n*th power, gives *r*. For given values of *r* and *n* there is only one such number. Now if *m* is any integer

$$\left[r^{1/n}\left\{\cos\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right) + j\sin\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right)\right\}\right]^n$$
$$= r\{\cos(\theta + 2m\pi) + j\sin(\theta + 2m\pi)\}$$

as already shown in Section 17. By drawing a simple quadrant diagram it will be easy to see that for all integral values of *m*

$$\cos(\theta + 2m\pi) = \cos\theta \text{ and } \sin(\theta + 2m\pi) = \sin\theta$$

so that

$$\left[r^{1/n}\left\{\cos\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right) + j\sin\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right)\right\}\right]$$
$$= r(\cos\theta + j\sin\theta)$$

and all the operators obtained by giving *m* any integral value in

$$r^{1/n}\left\{\cos\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right) + j\sin\left(\frac{\theta}{n} + \frac{2m\pi}{n}\right)\right\}$$

are *n*th roots of $r(\cos\theta + j\sin\theta)$. This seems rather a lot, but actually they are not all different. For instance if *n* is 3, then putting 0, 1, 2, 3 for *m* gives

$$r^{\frac{1}{3}}\{\cos(\theta/3) + j\sin(\theta/3)\}$$
$$r^{\frac{1}{3}}\left\{\cos\left(\frac{\theta}{3} + \frac{2\pi}{3}\right) + j\sin\left(\frac{\theta}{3} + \frac{2\pi}{3}\right)\right\}$$
$$r^{\frac{1}{3}}\left\{\cos\left(\frac{\theta}{3} + \frac{4\pi}{3}\right) + j\sin\left(\frac{\theta}{3} + \frac{4\pi}{3}\right)\right\}$$
$$r^{\frac{1}{3}}\left\{\cos\left(\frac{\theta}{3} + 2\pi\right) + j\sin\left(\frac{\theta}{3} + 2\pi\right)\right\}$$

But the last is a repetition of the first. It will be found that putting higher values for *m*, or giving it any negative integral value, will only give a repetition of one or other of the first three roots. In general there are only *n different* values of the *n*th root of any operator. Any reader to whom this is new should draw out the various operators in a simple case, say, for $n=3$. The geometrical significance of this many-valuedness will then be apparent. The value obtained by putting $m=0$ is called the "principal value," and is sometimes written $\{r(\cos\theta + j\sin\theta)\}^{1/n}$ the alternative form

$$\sqrt[n]{r(\cos\theta + j\sin\theta)}$$

being used to indicate all or any of the roots. The many-valuedness of the root sometimes enters into calculations and should always be borne in mind. The following are some important special cases. (*a*) If $\theta=0$

$$\sqrt[n]{r} = r^{1/n}\left(\cos\frac{2m\pi}{n} + j\sin\frac{2m\pi}{n}\right)$$
$$m = 0, 1, 2, \ldots n-1.$$

the principal value being $r^{1/n}$. If n is 2

$$\sqrt{r}=r^{\frac{1}{2}}(\cos 0+j\sin 0)\,;\ r^{\frac{1}{2}}(\cos \pi+j\sin \pi) = = +r^{\frac{1}{2}}\,;\ -r^{\frac{1}{2}}.$$

$$i.e.,\ \sqrt{r}=\pm r^{\frac{1}{2}}$$

(*b*) Putting $\theta=\pi$

$$\sqrt[n]{r\,(\cos \pi+j\sin \pi)} = \sqrt[n]{-r}$$
$$=r^{1/n}\left\{\cos\frac{(2m+1)\pi}{n}+j\sin\frac{(2m+1)\pi}{n}\right\}$$

and the principal value is

$$r^{1/n}\left\{\cos\frac{\pi}{n}+j\sin\frac{\pi}{n}\right\}$$

For instance, if n is 2

$$\sqrt[2]{-r}=r^{\frac{1}{2}}\left\{\cos\frac{\pi}{2}+j\sin\frac{\pi}{2}\right\}$$

or $$r^{\frac{1}{2}}\left\{\cos\frac{3\pi}{2}+j\sin\frac{3\pi}{2}\right\}$$
$$=\pm jr.$$

20. Generalisation of the Index Formula.

It has already been shown that for any positive or negative integral value of n

$$\{r(\cos\theta+j\sin\theta)\}^n = r^n(\cos n\theta+j\sin n\theta).$$

Also, by the preceding section, the same is true for the principal value when n is $1/m$, m being a positive integer. This leads without difficulty to the complete generalisation that for any positive or negative integral or fractional value of n, the principal value of

$\{r(\cos\theta+j\sin\theta)\}^n$ is $r^n(\cos n\theta+j\sin n\theta)$.

Space cannot be spared for a detailed development of this generalisation, which follows exactly the same lines as the generalisation of the interpretation of an index given in Part I (September, 1926.)

21. Calculations with Operators.

We have seen that any operator $(a+jb)$ can be put in the form $r\epsilon^{j\theta}$, where $r^2=a^2+b^2$ and θ is one of the angles having b/a as tangent. Referring to the quadrant diagram (Fig. 14) it will be seen that if a and b are positive, θ will be an angle in the first quadrant, *i.e.*, less than 90°. If b is positive and a negative θ will lie in the second quadrant, and so on. Writing $|b|$ and $|a|$ for the magnitudes of b and a, then the angle $\alpha=\tan^{-1}|b|/|a|$ is between 0 and 90 and can be determined from the ordinary table of tangents, and θ will be $+\alpha$, $\pi-\alpha$, $\pi+\alpha$, or $-\alpha$ according to whether it is in the first, second, third or fourth quadrant. An example will perhaps make this clearer. For the operator $3-j4$, r is 5 and θ is an angle in the fourth quadrant. Now $\tan 4/3$ is 53.1°, so that θ is $-53.1°$. For the operator $-3+j4$, on the other hand, θ will be in the second quadrant, so that it is given by $(180-53.1)°$, *i.e.*, 126.9°.

By using the form $r\epsilon^{j\theta}$ the single operator which is equal to, *i.e.*, has the same effect as, any given combination of operators, can be written down at once. For instance, if

$$a+jb=r\epsilon^{j\theta}$$
$$c+jd=s\epsilon^{j\phi}$$

then

$$(a+jb)^2/(c+jd)=(r\epsilon^{j\theta})^2/s\epsilon^{j\phi}=r^2\epsilon^{j2\theta}/s\epsilon^{j\phi}$$
$$=(r^2/s)\epsilon^{j(2\theta-\phi)}$$

which can then be put in the form $A+jB$ if desired, where

$$A=(r^2/s)\cos(2\theta-\phi)$$
$$B=(r^2/s)\sin(2\theta-\phi)$$

A simple type of calculation which will occur frequently in alternating current calculations is exemplified by the following.

Given that $\mathbf{e}=\hat{e}\epsilon^{j\omega t}\nu$

and that $\mathbf{i}=\mathbf{e}/(R+jX)$

R and X being numbers, find $\mathbf{i}\cdot\nu$.

Notice that

$$\mathbf{e}\cdot\nu=\hat{e}\epsilon^{j\omega t}\nu\cdot\nu=\hat{e}\cos\omega t$$

is the instantaneous value of an alternating E.M.F. It will be shown later that $\mathbf{i}\cdot\nu$ is similarly the instantaneous value of the "steady state" alternating current produced by this E.M.F. in a circuit of impedance $(R+jX)$. Expressing this impedance in the form

$$R+jX=Z\epsilon^{j\phi}$$

where $Z^2=R^2+X^2$ and $\tan\phi=X/R$

then

$$\mathbf{i}=\frac{\mathbf{e}}{R+jX}=\frac{e\epsilon^{j\omega t}}{Z\epsilon^{j\phi}}\nu=\frac{\hat{e}}{Z}\epsilon^{j(\omega t-\phi)}\nu$$

so that

$$\mathbf{i}\cdot\nu=(\hat{e}/Z)\epsilon^{j(\omega t-\phi)}\nu\cdot\nu=(\hat{e}/Z)\cos(\omega t-\phi).$$

An alternative form for this result may sometimes be more convenient. The reciprocal of $(R+jX)$ can be expressed in the form

$$\frac{1}{(R+jX)}=\frac{R-jX}{R^2+X^2}=\frac{R}{Z^2}-\frac{jX}{Z^2}=\frac{R}{Z^2}+\frac{X}{Z^2}\epsilon^{-j\pi/2}$$

since $-j=\epsilon^{-j\pi/2}$.

Therefore

$$\mathbf{i}\cdot\nu=(R/Z^2)\,\hat{e}\epsilon^{j\omega t}\nu\cdot\nu+(X/Z^2)\,\hat{e}\epsilon^{j\omega t}\epsilon^{-j\pi/2}\nu\cdot\nu$$
$$=(R/Z^2)\,\hat{e}\cos\omega t+(X/Z^2)\,\hat{e}\cos(\omega t-\pi/2)$$
$$=(R/Z^2)\,\hat{e}\cos\omega t+(X/Z^2)\,\hat{e}\sin\omega t.$$

So much for a brief introductory survey of the main features of vectors and vector operators. The more detailed study of the subject will be confined to those regions where it comes into immediate contact with the field of alternating current phenomena, in the discussion of which it will be found to infuse a beautiful simplicity; but first we must see how it comes to be associated with what would at first sight seem to be a quite different set of ideas. The nature of the connection has already been foreshadowed, but for its complete delineation some little knowledge of the differential and integral calculus will be required, and to this branch of mathematics the next part of this series will be devoted.

Answers to Examples in June Issue.

1. (i.) 60°. (ii.) 8° 11′. (iii.) .17 radians. (iv.) 22 radians.

2. (i.) 88.8 units of area. (ii.) 25 units of area.

3. The unit of area is increased in the ratio π : 1. The number of units in a given area will therefore be reduced in the same ratio.

(i.) 28.26 units of area. (ii.) 7.95 units of area.

4. (i.) 14.55 cms. at 39.9°. (ii.) 6.197 cms. at 186.2°. (iii.) 43.3 cms.^{2} (iv.) 146° 18′; 75 cms.^{2} (v.) 211.7 cms.^{2} (vi.) 38.4 cms.^{2}

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

H.T. and L.T. from a 250-volt D.C. Supply.

To the Editor, E.W. & W.E.

SIR,—Mr. E. J. Baty has raised a few points in connection with my article on the above subject (*E.W. & W.E.*, p. 111, February, 1927). The double circuit tuner was not adopted for the purpose of assisting the smoothing of hum, as he suggests, but to prevent the aerial from becoming alive, which, with a single coil tuner, would attain a potential of 130 volts when the H.T. supply is taken from a 250-volt main with the + side earthed.

The apparatus described in Fig. 2 is used in conjunction with a three-valve multi circuit receiver which embodies several types of valve coupling including tuned anode, resistance capacity and transformer coupling. The arrangement permits an instantaneous change over to be made from one combination to another. Various types of tuner were tried out and experimental results proved the single coil tuner to be fully as good as the double circuit.

If the user does not object to a "live" aerial there is no reason why he should not use a single coil tuner if he so desires.

The resistance capacity circuit was found to be the most sensitive as regards picking up of the town main hum, particularly when a high impedance valve was used as a detector. This was most noticeable when a certain rotary converter was running in the sub-station in which there appeared to be at least three types of convertor each having a totally different ripple characteristic.

I agree with your correspondent that, in the arrangement he describes, two chokes would be better than one of the same total value and that the condensers between the H.T. + and H.T. — contribute towards smoothing, but I do not agree that this is the case in the potentiometer system, described in the article referred to, where only one choke coil is necessary provided it is situated at the "live" town main terminal. The reservoir condensers in this case perform very little smoothing. I would advise your correspondent that the H.T. positive should on no account be connected to earth but should be connected to the neutral main.

I agree that for ordinary broadcast receivers there is no necessity to employ 12 lamps in series in the potentiometer, probably three lamps of a correspondingly higher resistance would suffice, but for experimental purposes it is necessary to have a wider range of voltage available and it is desirable that this supply should be reasonably constant irrespective of the demands of several valves in a receiver. The potentiometer method is much superior, in this respect, to the resistance arrangement, described by Mr. Baty, the voltage of which will vary considerably according to the load and will automatically rise to that of the town supply mains when all the valves are switched out. Mr. Baty makes the statement that no supply company would allow the apparatus to be used on the low rate of 1d. per unit. He is doubtless unaware that in Glasgow a special tariff is allowed to domestic consumers, under which electrical energy for

lighting and domestic appliances is measured by a single meter. A fixed number of units is charged at the rate of 4½d. per unit and all further units at ¾d. per unit. My electricity bill for the corresponding period of last year (9th February—11th May) was as follows :—

	13 units at	4½d. =	4s.	11d.
	227 ,,	,, ¾d. =	14s.	2d.
Total	240 ,,	cost	19s.	1d.

which is even less than the 1d. per unit mentioned.

Your correspondent holds the opinion that the L.T. should be kept clear from the town mains entirely but if he intends using this supply for his H.T. I am afraid this is impossible as the L.T. must necessarily be connected to the town mains through the H.T. negative. No further risk would be introduced by going a step further and using this supply for charging the L.T. battery while the receiver is in operation. There is no undue risk in lighting the valve filaments from the town mains, in series with the potentiometer, when all the valves are run in series. Your correspondent may be surprised to learn that I have not yet burned out a valve filament.

An advantage of the arrangement just described is that a receiver can be switched on by means of a tumbler switch and loud-speaker reception obtained when desired. No battery of any kind would be required; grid bias being obtained by means of a small resistance connected at the negative filament supply. By means of a second switch connected to a suitable tapping on A.T.I. an alternative station can be obtained on loud speaker. The success of this arrangement will of course depend upon the locality in which the receiver is situated. The writer experiences no difficulty in changing over from Glasgow to either Belfast or Dublin by means of this switch without any further tuning.

Glasgow. A. ROBERTSON.

That Audio Transformer Problem.

To the Editor, E.W. & W.E.

SIR,—My object in this correspondence has been to show that the general principle of equality of anode impedance with the given impedance of the valve for maximum amplification at a given frequency is not inapplicable to the case of the volt-amplification of an *audio*-frequency valve-transformer combination, and that we are, in fact, in progressively increasing the inductance of the transformer primary with the object of improving low note reproduction, knowingly or unknowingly applying this principle at progressively lower frequencies.

It has been somewhat of a surprise to me that my various critics have not seen this matter in the aspect which, I submit, is undoubtedly the correct one, and I am hoping that my answers contained in this letter to points raised in the contributions of your correspondents, Messrs. T. R. Lupton and J. Baggs in your April and May issues respectively, will supply the necessary additions to my previous explanations.

The discussion centres largely round the successful amplification of low audio frequencies, in which direction some simplification arises from the fact that parallel capacity and eddy current effects become of relatively small magnitude. Hysteresis, it is true, remains, but can be shown not to affect materially the general argument.

As the inductance of the primary winding in a given winding space is progressively increased, the frequency at which its impedance is equal to that of the valve becomes progressively lower and lower. At each such frequency the winding is for the moment such that its ampere turn effect, and therefore the amplification for that particular frequency have reached their maxima (approximately when parallel capacity is present) and if the inductance be further increased, the amplification at that frequency would again become reduced; that at all higher frequencies would become still further reduced than previously and that at any lower frequency would be rising towards its maximum. In so far, therefore, as it were true to say that we require to amplify an indefinitely low frequency, it would be correct to say that we require to use the highest possible primary inductance. We do not, however, require to amplify indefinitely low frequencies.

The remarks contained in Mr. Baggs's third paragraph are agreed to—the 0.707 figure on the assumption of negligible winding resistance and capacity—nevertheless for the moment the primary ampere-turns, and therefore the amplification for the particular frequency referred to, are at their maxima and any further increase in primary inductance will reduce these, and those of higher frequencies still more, bringing the amplification ratios for these various frequencies more nearly the same, it is true, but nevertheless reducing the amplification on all these frequencies. Though the voltage applied to the primary increases, the number of turns increases in a greater proportion and the exciting ampere turns and volts per turn fall. Only the amplification of lower frequencies will be increased. The point is that we cannot, with the idea of rendering the amplification at all frequencies (low and moderately high) more and more nearly equal, increase the primary inductance unduly, because by so doing we are reducing the general amplification to such an extent as to be out of the question.

So much depends upon what interpretation is put upon the expression "highest possible (primary) impedance."

My objection to that expression is that it has undoubtedly been used by my critics to imply the maximum inductance that is technically possible mechanically, *vide* Mr. Baggs's fourth paragraph and the various other references to making this infinitely great. In advocating indefinitely great primary inductances, they appear to lose sight of the questions of the secondary and transformer ratio. The utilisation of the whole of the amplification factor μ of the valve, or of the whole amplified voltage, is *not* the correct aim, except indirectly for uniform amplification at various frequencies, and it is scarcely correct to say in this case (as it would be more reasonable to do in the case of a power transformer on open circuit) that "the secondary winding merely steps up the

voltage applied across the primary" as if the transformer ratio remained constant when we alter the primary winding and there were no external resistance in series with it.

My objection is also that there appears to be no reason why the primary winding should not be wound of equal fineness with the secondary, producing say a 1 to 1 transformer, thereby seriously reducing the overall amplification on all required notes. It should be clear, therefore, that it is out of the question to utilise the "highest possible primary impedance" in the generally accepted sense, and that the limit of primary inductance depends upon the valve used, being lower for a lower impedance valve. The way in which the matter must be viewed is to settle upon some low frequency in the region of the lowest which we desire to amplify, and to arrange the primary inductance so that its impedance at that frequency will be equal to that of the valve, in which case the primary winding will correspond to a maximum amplification for that particular frequency.

There is not, as suggested by Mr. Baggs, any confusion of requirements of a good high and a good low frequency amplifier. It is quite true that we do not want a low frequency amplifier to amplify one frequency particularly, but we do want maximum amplification of a selected low frequency, and it is at that low frequency that the principle of equality is applicable, and *only a percentage of the voltage used*. The lower this selected frequency the more nearly uniform the amplification over the audio range of frequencies, except as regards high frequency limitations mentioned by himself, but there is a natural limit beyond which the gain of uniformity is not worth the loss of general amplification. This general amplification at the higher frequencies is very much less than it could be, because the impedance at those frequencies, or the tuned impedance when the reactance becomes capacitive, is so much higher than that of the valve.

I would remind Mr. Baggs concerning his second paragraph, that it is not "energy" (watts) that is required in a H.F. primary but activity (volt-amperes). We can have more of the latter with less of the former with improved result.

With regard to Mr. Lupton's letter :—

1. All my statements have clearly referred to valve plus transformer combination, the valve being given and the transformer windings variable. Mr. Lupton will see that the word "valve" was used in my statements 1 and 3.

2. The power transformer problem is a different one involving as it does the transformer only—with a given primary voltage and no questions of series resistance and maximum amplification. Several power transformers have been designed and made by the writer.

3. The erroneous parts of recent advertisements should be clear from explanations herein contained.

4. The problem of the primary of the output transformer is the same in relation to its valve as in the case of the stage transformer. Owing to the use of a power valve, its primary impedance at any given frequency can be lower.

We are all agreed as to the improvement in results by increasing the primary inductance of a transformer *up to a certain point*, the reason being that it increases the amplification of progressively lower and lower notes, and so gives more foundation to the reproduced music. In spite of the fact that the amplification of the higher frequencies is reduced, the general volume of reproduction does not, up to that point, appear to be reduced. If, however, the inductance be too far increased, then although quality may remain good provided high frequency effects are correct, the general amplification of the transformer will go down and the transformer will be incorrect. It is an easy experiment to try a transformer the wrong way round to realise this effect.

The reason for the non-appreciation by my critics of the application of the fundamental equality principle appears to have been the fact of the necessity of applying the principle not to an average frequency of the audio range, but to a very low frequency in that range, thus resulting in a high (but not indefinitely high) primary inductance.

The reasons of this necessity may be said to be :—

(*a*) The optimum amplification for any given frequency is, with some qualifications, much larger for the higher frequencies.

(*b*) The space factor of the primary winding gets worse as the winding is made finer, putting the resistance up disproportionately.

(*c*) At low and lower frequencies, a *given transformer* requires more than proportionately more magnetising ampere turns for the same primary P.D. so that the resistance effect of the circuit is disproportionately enhanced and the amplification falls rapidly, whereas at higher frequencies the amplification remains roughly constant as the frequency increases until pulled down by capacity, etc., effects.

(*d*) The actual amplitude of potential swing on the low frequencies is on the average greater than that at high frequencies, still further increasing the (*c*) effect.

(*e*) Loud speakers of types which are not very low pitched, and therefore not readily capable of reproducing low notes, require for better musical effect as much stimulus on low frequencies as possible.

May I thank you, sir, for the space you have devoted in various recent issues to my contributions on this subject

You have permitted me to refer to a small error which crept into my contribution in your February issue. The word "changes" on p. 302 (first paragraph) should have been "lowers."

E. Fowler Clark,
B.Sc., B.A., A.M.I.E.E.

A Wireless Works Laboratory.

Paper read by Mr. P. K. TURNER, A.M.I.E.E., before the Wireless Section, I.E.E., on 18th May, 1927.

ABSTRACT.

IN opening this, the final meeting of the Session for the Wireless Section, the Chairman, Mr. E. H. Shaughnessy, O.B.E., announced that premiums had been awarded to Mr. T. L. Eckersley, and (jointly) to Dr. R. V. Hansford and Mr. H. Faulkner, for papers read during the Session.* He also announced the nomination of Lieut.-Colonel A. G. Lee as Chairman for the next Session.

The paper describes the equipment of the Laboratory of the Research Department of Messrs. Burndept Wireless, Ltd.

1. Functions. †

The functions of the Laboratory are stated by the author to be: Development work on, and electrical design of, all new apparatus for the firm; building first samples and examining first production models, examining apparatus of other makers; building apparatus for the department which does routine testing of production apparatus, etc.

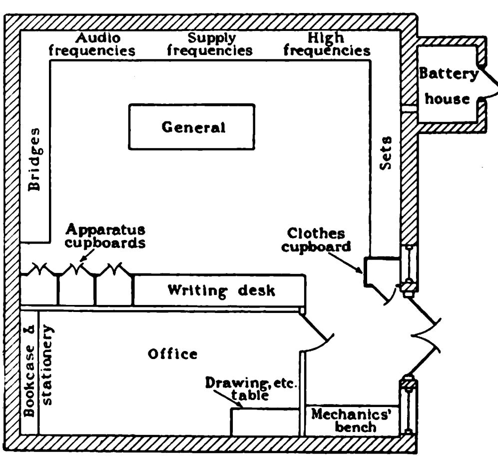


Fig. 1.

2. Location and General Arrangements.

The Laboratory is located on the flat roof of the works. To provide maximum wall space there are no windows, roof lighting being ample. Fig. 1 shows the general lay-out The various parts of the main work bench are not strictly reserved, the location of any particular job being selected according to whether any fixed apparatus is to be used.

3. D.C. Work.

(A) *D.C. Supply.*—Since the majority of the work is on valves and valve circuits, a suitable D.C. supply was practically the first matter to be considered. Secondary batteries were decided upon (except possibly for grid biasing), and it was also decided to make battery power available everywhere on permanent wiring.

It was believed that by care in arranging the wiring, and by the use of by-pass condensers, mutual interference could be avoided.

The batteries actually installed are :—

Voltage.	Amp. hours.	No.	Total voltage.	
2	50	2	4	
6	50	8	48	
2–6	50	4	24 (max.)	
6	100	1	6	
2–20	50	1	20 (max.)	
				102V, 5A
50	1	4	200	
100	1	2	200	
60 or 80–120	1	5	600 (max.)	
				1,000V, 0.1A
10–100	5	1	100 (max.)	
50–400	5	1	400 (max.)	
				500V, 0.5A
				1,602V

The main points of the distribution scheme are shown in Fig. 4, the central feature being the intermediate distribution frame adapted from telephone practice. At intervals along the backboard of the working bench are switch boxes, as in the photo, giving from two to five supplies, with leads to sockets on the distribution frame.

(B) *Measuring Instruments and Standards.*—It has been found important to have plenty of rough instruments in the form of cheap moving coil meters of 3 in. dial of 0—1mA to 0—5A and from 0—12 to 0—120V. Accurate D.C. meters comprise a " Century " testing set (Elliott Bros.) and a large Weston meter of 0-2 to 1-1,000V and 0-20mA to 0-40A. " Unipivots " of 0-240 and 0-24μA are also extremely useful.

An anti-vibration method of mounting reflecting galvanometers is described and illustrated, and the author also described a new pattern of lamp and projection system for use with these instruments.

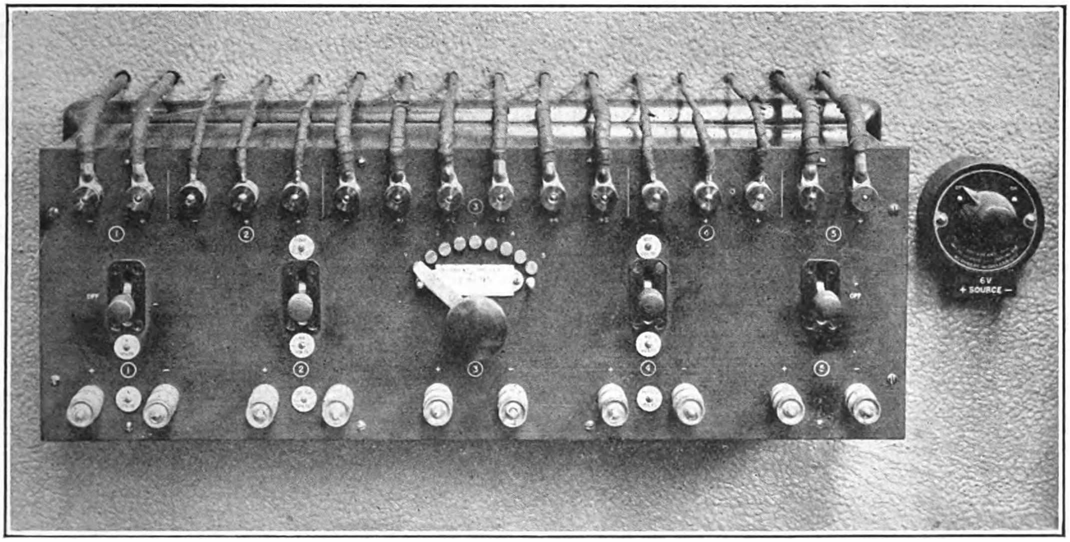
(C) *Resistors.*—A varied assortment of resistors, rheostats, etc., was found necessary. A useful item is a decade box of accuracy 1/3,000 and accurate

* See Abstracts in *E.W. & W.E.*, January, 1927, and April, 1927.

† The author's original section numbers and figure numbers are adhered to throughout this Abstract.

to 0.5 per cent. at 1,000,000 cycles. Standards are four resistors, nominally 1, 10, 100 and 1,000 ohms, oil sealed and checked to high accuracy at the N.P.L.

and anode current to rise. The time taken for the pointer to move between definite marks is multiplied by a constant and divided by the capacity, to give megohms. It is essential that the circuit shown



Showing the switch boxes for obtaining various supplies on the benches.

in heavy lines should have very high insulation; in the instrument described this is of the order of 50,000 to 100,000 megohms. The instrument has a range of about 50—50,000 megohms on condensers of $1 \mu F$.

(D) *Bridge*.—The D.C. resistance bridge is also an A.C. bridge and is described later.

(E) *Condenser Tests*.—Fig. 11 shows a valve method of testing condenser leakage. With the key up the valve is biased to —9V. and the condenser charged to 109V. On pressing the key the condenser discharges through its own leakage in parallel with the apparatus causing the grid potential

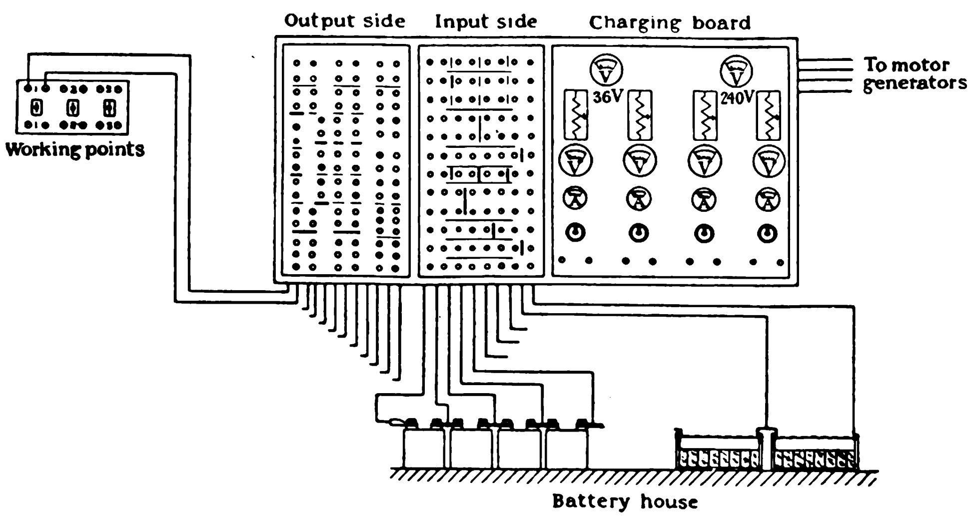


Fig. 4.

(F) *Valve Tester*.—After considering dynamic methods of finding the A.C. resistance and amplification constant, it was decided that no method is

so satisfactory as an actual plot of the characteristic. An instrument was therefore produced simply to apply definite D.C. potentials and measure the resultant currents. The schematic diagram is shown in Fig. 12, while the following ranges are given by the range switches :—

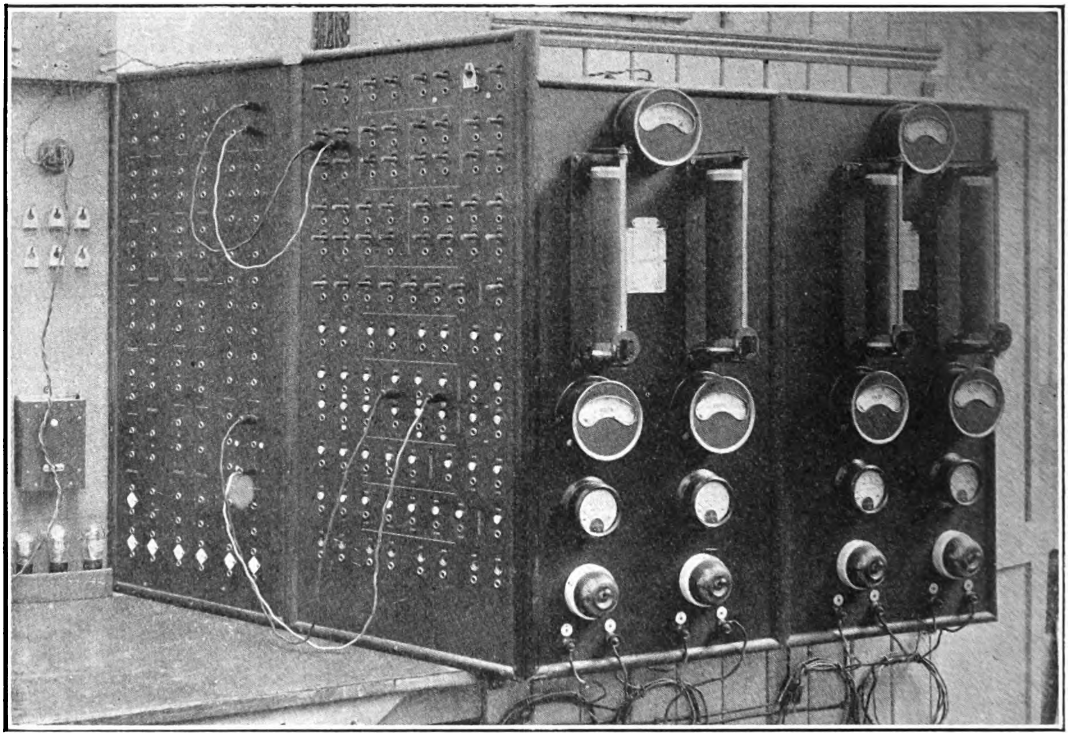
Anode current : 0-1, 5, 20, 100, 500mA.
Anode voltage : 0-25, 125, 250, 1.250V.
Filament current : 0-0.1, 0.25, 1.25, 2.5A.
Filament voltage : 0-2.5, 12.5V.
Grid voltage : 0-2.5, 12.5, 25, 125V.

4. Supply Frequency Work.

(A) *Supply and Instruments.*—A very useful meter, which is the Laboratory's standard for both A.C. and high frequency work, is a multirange thermal meter by the Cambridge Co. It embodies a set of vacuum thermojunctions and Unipivot millivoltmeter, and has ranges of 0—10 to 0—1,100mA with a pure resistive impedance which is fairly low and accurately known. It can be simply and accurately calibrated on D.C., the reverse effects being negligible. In series with resistance up to 10,000 ohms, it can also be used for calibrating A.C. voltmeters.

For the measurement of A.C. voltage, considerable use is made of a "diode voltmeter." There are two of these, one being a separate instrument, while the other is permanently connected as part of the low-voltage A.C. supply board.

(B) *Wattmeter.*—For measurement of rather small A.C. power a special Elliott wattmeter is provided indicating 11 to 44 watts at full scale.



Showing the battery supply panels and charging board.

5. Audio-Frequency Work.

(A) *Source.*—For the Laboratory work it was essential to have a practically pure note. This has been obtained by the now well-known method of using the rectified beats from two heterodyning oscillators. The author's arrangement is shown in Fig.16, where (1) is the "weak" oscillator of fixed frequency. Its output is weakly coupled to the

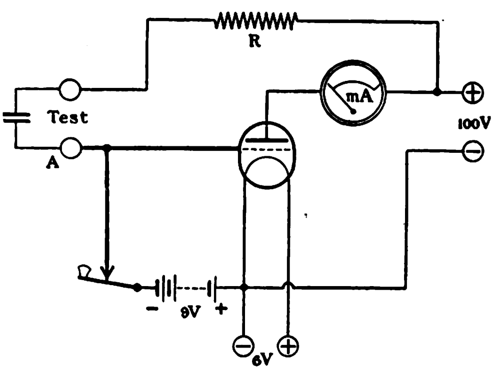


Fig. 11.

tuned and neutralised amplifier (2), which is, in turn, loosely coupled to the rectifier 4. It is thus practically impossible for the output of the "strong" oscillator (3) to get back via the detector coupling and affect (1). Until (2) was neutralised, it was not found possible to work down to really low frequencies without "pulling-in" effects. The beating frequencies used in the author's source are of the order of 300kC. The weak couplings and sharp tuning of (2) effectively weed out the harmonics of (1), which, if allowed to reach (4) would combine with the harmonics of (3) to give multiples of the desired beat frequency.

It is estimated that in its final form the source has no harmonic exceeding 3 per cent. of the fundamental.

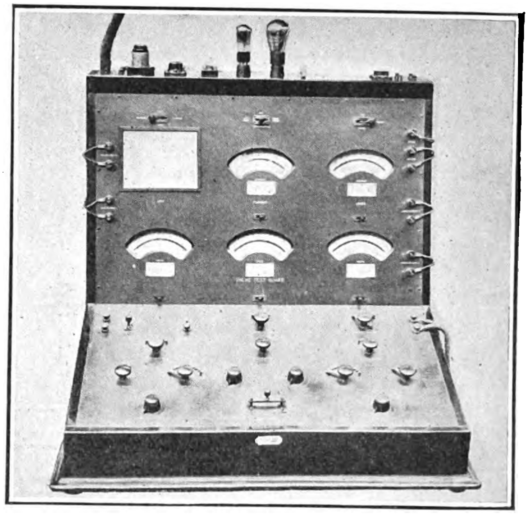
(B) *Voltage and Current.*—For measuring audio-frequency currents the multi-range thermojunctions instrument already referred to, is used, but it is usually found preferable to measure voltages rather than currents, by using valve voltmeters. This is, of course, on account of the much smaller power absorbed by the valve voltmeter. Such voltmeters are frequently merely bench assembled for a particular job, but a standard valve voltmeter is kept permanently assembled. The author formulates the following conditions for the instrument :—

1. To secure sensitivity, the indicator should be a multi-range instrument, and after "setting" the valve to reproduce the conditions of calibration, the steady anode current should be balanced out and the indicator "unshunted" if necessary.

2. To secure low power consumption and independence of frequency the grid should be connected directly to the circuit to be measured, and ample bias used.

3. To secure permanence of calibration, the valve should be bombarded, not "gettered."

The circuit is shown in Fig. 19, the valve being a bombarded one taking half an ampere at 4V. The normal anode current (used in calibration) is 40μA, and small deviations of operating voltage can be corrected by adjustment of R_g. Balancing-out current is then switched on at A and R_1 adjusted until the indicator returns to zero. In use as a voltmeter, the instrument behaves as a capacity of about 12$\mu\mu$F, with a power factor of 0.01 approximately.



Apparatus for taking valve characteristics.

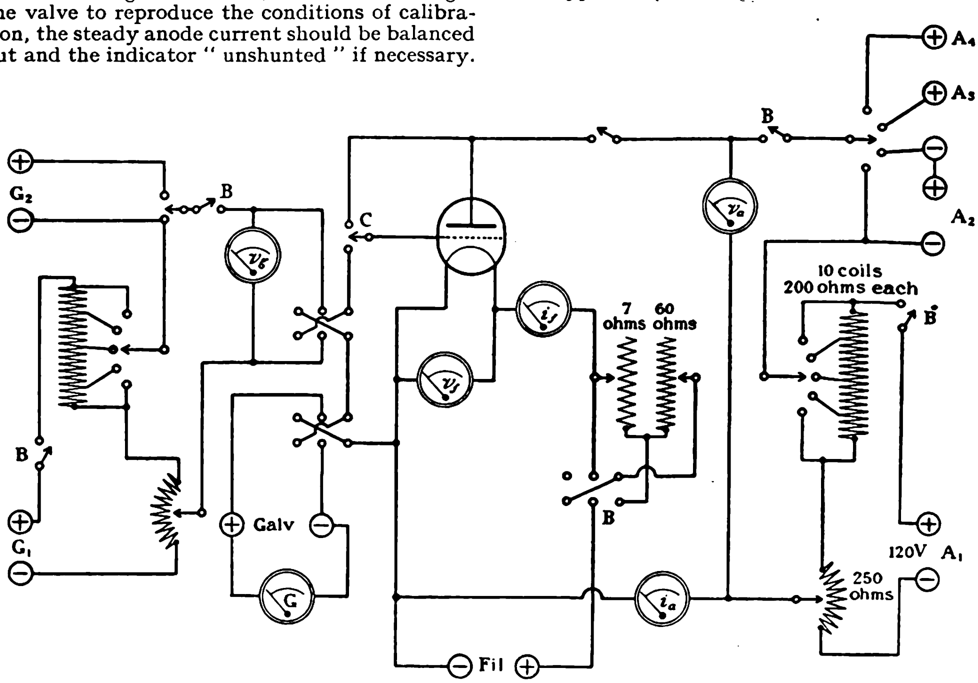


Fig. 12.

(c) *Capacity Bridges.*—Two such bridges are in use, the basic standards being variable condensers, instead of mutual inductors. This is done on account of the power factor of inductors at high

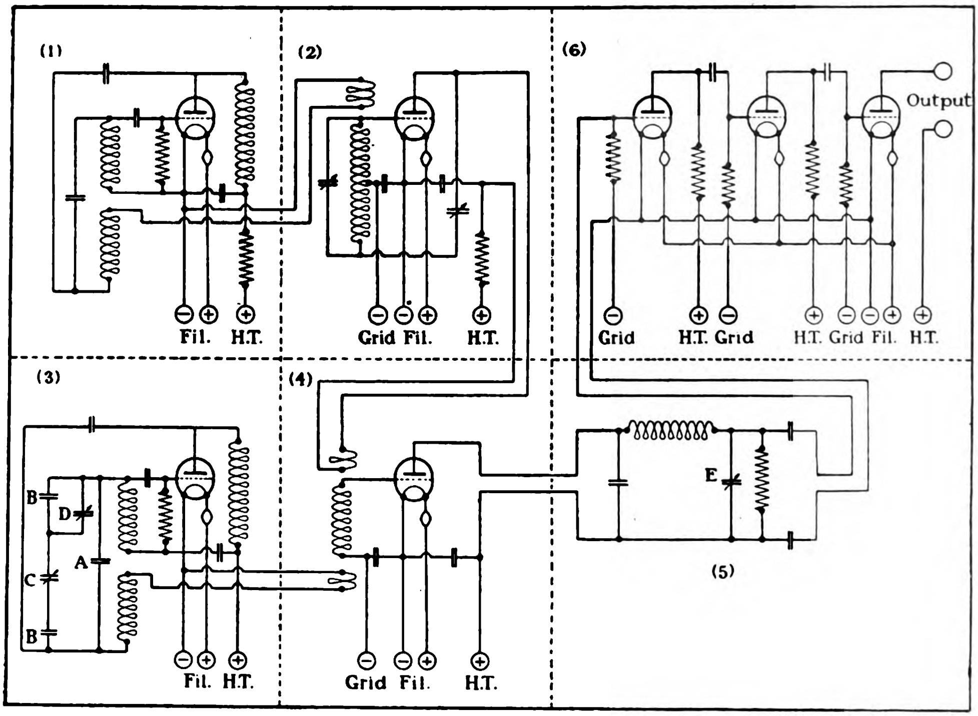


Fig. 16.

frequencies, the power factor of a good condenser being approximately independent of frequency, and readily checked at the N.P.L. Details are given of the variable condensers used.

(D) *Combined A.C. and D.C. Bridge.*—A very useful bridge is that shown in Figs. 21 and 22. It is of very wide range, permitting measurement of inductance from 100μH to 100H; capacity from 0.001μF to 10μ and also of D.C. resistance. The circuit is that of an Anderson bridge, as in Fig. 21. *A* and *B* can each be made, 1, 3, 10, 30, 100, 300 or 1,000 ohms, and P., Q. and M. are variable by single ohms up to 10,000. The lower end of the variable condenser can also be joined alternatively to the junction *Bx* where it permits the measurement of unknowns having a capacitive reactance. The full circuit showing the relay change over methods of changing from A.C. to D.C. and *vice versa* are shown in Fig 22. The resistance arms are accurate to 0 1 per cent. on D.C. and 0.5 per cent. at 1,500kC.

The author then refers to the difficulty of measuring iron-cored inductors which also carry a polarising current. He therefore suggests the circuit of Fig. 23, where the inductances in the sub-bridge are either equal or one of them is known. The balance of the sub-bridge for D.C. can be adjusted by using the galvanometer of the main bridge. The sub-bridge is not necessarily balanced for A.C.; the current through one coil can be calculated in terms of that shown in the A.C. meter.

(E) *Frequency Measurement.*—As the L.F. source described cannot be relied upon for constancy from day to day, a monochord or stretched-wire frequency meter (on lines due to Dr. D. W. Dye) has been built. The wire carries the current from the

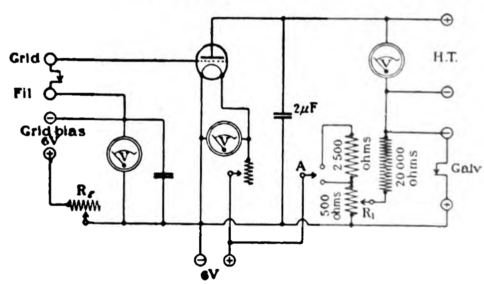


Fig. 19.

source and is made to vibrate by passing through the air gap of a magnet. The natural frequency is adjusted by moving the lower bridge and so altering the effective length.

(F) *Audio-frequency Measurements carried out.*—The audio source and valve voltmeter have been

used to measure the amplification of a stage as shown in Fig. 25. R_1 and R_2 are adjusted to a ratio suitable for the amplification to be measured and R_3 is adjusted until the voltmeter remains unmoved on throwing over the switch *A*. For a given input the A.C. component through R_3 is thus known; and the amplification can be calculated.

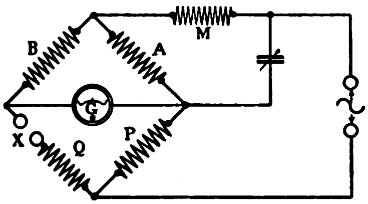


Fig. 21.

6. Radio-Frequency Work.

(A) *Sources and Voltage, etc., Measurement.*—The multi-range vacuo junction meter can be used for the measurement of radio frequency currents, but it is as a rule, preferred to calculate these currents by observing, with the valve voltmeter, the voltage across a known reactance or resistance.

(B) *Frequency.*—The laboratory has a standard wavemeter in the form of an oscillator of normal type, but arranged so that the conditions of calibration are easily reproduced. The calibration is checked from time to time against the N.P.L. standard waves.

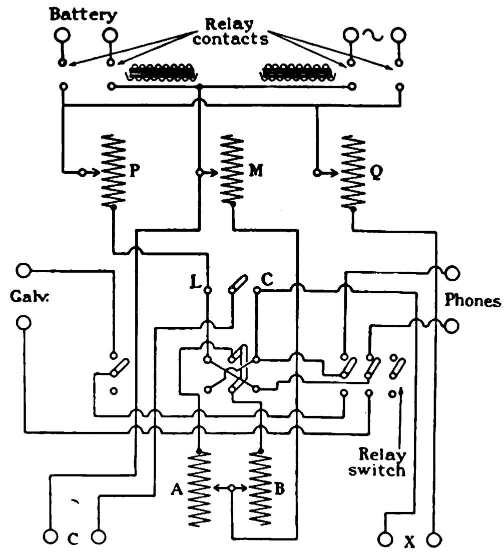
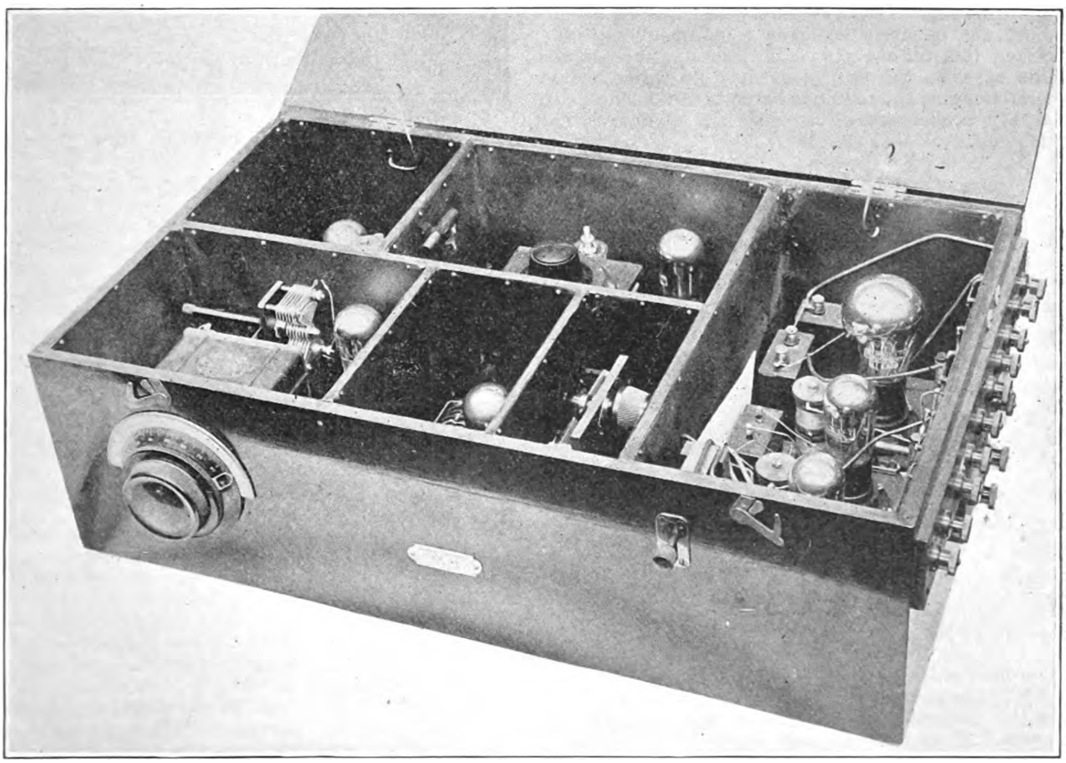


Fig. 22.



A view of the heterodyne L.F. oscillator.

(c) *Capacity and Inductance.* — Condensers are only measured at radio frequencies when the value is expected to differ from that at lower frequencies. Self-capacities are usually measured at radio frequencies. This is done in the usual manner by a series of measurements of resonant frequency with different external capacities, the valve voltmeter being used as a resonance indicator. The author illustrates the method for the determination of self-capacity due to Mr. W. A. Barclay who has contributed various notes on such methods to *E.W. & W.E.* Each reading of λ against external capacity is plotted as a straight line. These should meet in a point, but actually they form a small polygon of error. A line drawn from the λ zero through the polygon will meet the capacity scale at a point above zero, giving the self-capacity. If desired, the diagonal line between the two zeros may be calibrated in microhenries, the readings being taken on the point of the scale vertically below the centre of the polygon.

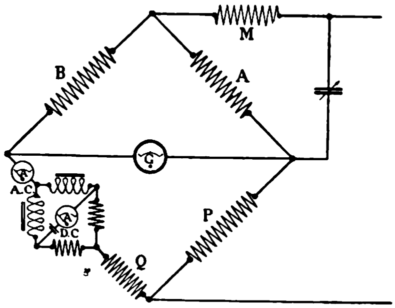
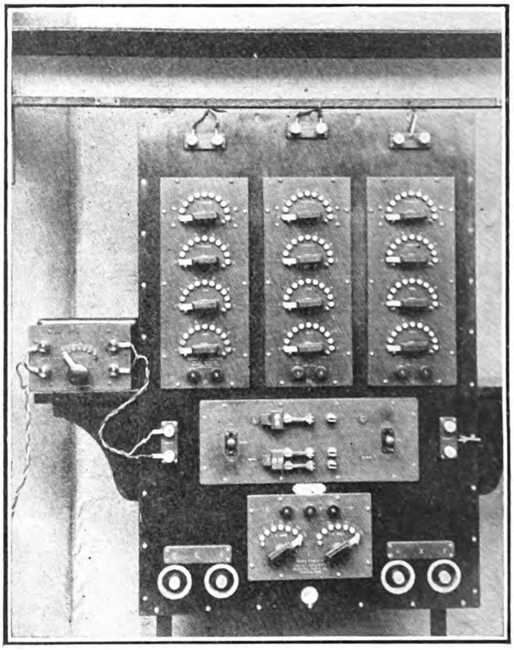


Fig. 23.

employed, with terminals for coil socket, straps for condenser and valve voltmeter, and a socket for the insertion of a special fixed high-frequency resistor, the construction of which is illustrated in the paper.



The combined A.C. and D.C. bridge.

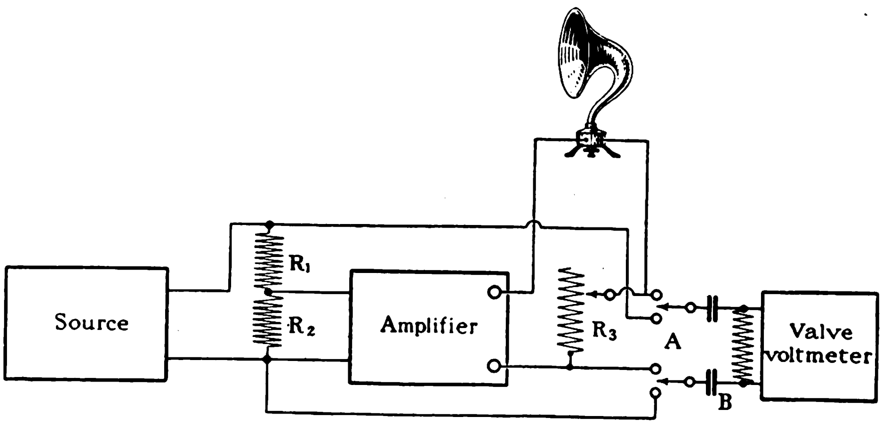


Fig. 25.

(D) *Resistance.*—The resistance-variation method is used, the total resistance of the circuit being measured and correction made for resistances outside the coil. A special connection box is

After finding, by the usual method, the resistance of the whole circuit, corrections are made for losses in various parts of it. From the results of various tests it appears that these losses all enter as if

they were due to small condensers of high power factor. As examples, there are the following :—

	Capa-city, $\mu\mu$F.	Power factor.	$\frac{\psi C_s}{0.1885}$
Standard valve voltmeter	12.4	0.0096	0.63
Connection box ...	14.4	0.0104	0.80
Coil holder	2.4	0.0254	0.32

The last column gives a factor which is convenient in converting the loss into apparent series ohms in any given resonant circuit.

If C_s = capacity of accessory, as in col. 2 of above table,
ψ = power factor of accessory, as in col. 3 of above table,
C_t = total capacity (= condenser + self-capacity of coil and all accessories) in $\mu\mu$F,
λ = wavelength,
R' = apparent series resistance due to the accessory,

then $$R' = \frac{\psi C_s}{0.1885} \times \frac{100\lambda}{C_t^2} \text{ ohms.}$$

In a typical case, where $C_t = 250\mu\mu$F, $\lambda = 400$ metres, $R' = 1.12$ ohms for all the accessories together.

(During the reading of the paper, the audio-frequency source was demonstrated, and several other of the instruments described were on exhibition.)

DISCUSSION.

A lengthy discussion followed the reading of the paper.

Mr. L. B. Turner first referred to the neat method of the "polygon of error" for the determination of self-capacity, and to the neutralised triode in the amplifier used in the low frequency source. He thought that the information on this source could be added to by more experimental data. With reference to Fig. 23, he did not think the internal bridge arrangement was necessary, and outlined a simpler bridge circuit. Lastly he discussed arrangements for D.C. supply, illustrating the arrangements used in the Engineering Laboratory at Cambridge, with the precautionary devices employed.

Mr. P. R. Coursey expressed interest in the paper, since he was connected with a commercial laboratory for a similar type of work. He then dealt with the D.C. supply arrangements in this laboratory, showing slides which illustrated the switchboards, etc., for voltage supplies, low tension and high tension. With reference to the condenser leakage testing arrangement, he sketched another circuit for this test, shown in Fig. A. This was a very useful method for a quick test, and the leakage test was a more useful specification of performance than was a mere statement of megohms. He also discussed the heterodyne L.F. source as compared with a coupled generator.

Mr. P. W. Willans first referred to the general difficulty of "mush" in a works laboratory. He asked for information as to the capacity effects of long battery leads, especially in a non-earthed circuit. Regarding value tests, he noted that only D.C. characteristics were used, but suggested the need of dynamic characteristics also. In measurement of amplification he urged the need for the use of vector methods, as well as scalar. Lastly he dealt with the measurement of high frequency resistance, and described a resonance method of measurement.

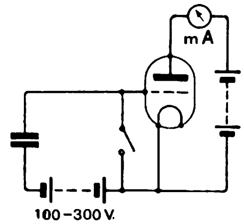


Fig. A.

Prof. McClinton referred briefly to a plug-board system of battery distribution, employing no flexible connections. Such a scheme had been in use for 20 years without a single short circuit.

Captain H. J. Round referred to the heterodyne generator as an L.F. source and to its use in conjunction with a method of measuring air pressures for loud-speaker tests, etc.

Mr. E. B. Moullin sought information on several points, more especially why single scale instruments were used, the accuracy of the General Radio high frequency resistors, use of wattmeter, etc.

Mr. J. H. Reyner did not think the methods described were too precise. He discussed several points in connection with the L.F. source, and dealt with the use of the quartz crystal as a frequency standard, illustrating a method of using the crystal for the measurement of frequency and capacity.

Mr. Bainbridge Bell described experiences of "mush" in a works laboratory, when improvement had been effected by the electrical bonding of shafting supports.

Mr. MacPherson discussed the L.F. source as against a coupled oscillator, and said he had had a satisfactory oscillator working as low as 15 cycles. He had found that a great deal of "mush" could be cured by enclosing the apparatus in a wire netting screen.

The author briefly replied to several of the matters raised in the discussion, and on the motion of the Chairman (Mr. E. H. Shaughnessy, O.B.E.) was accorded a hearty vote of thanks for his paper.

The Internal Action and Principles of Design of Thermionic Valves.

A Lecture before the Radio Society of Great Britain by A. C. BARTLETT, delivered at the Institution of Electrical Engineers, on Wednesday, 20th April, 1927.

I PROPOSE to speak to-night chiefly of the internal action of valves and of some of the points that present themselves in the design of larger types and to point out that the design of thermionic valves is by no means empirical but is a quite well-developed branch of electrical engineering.

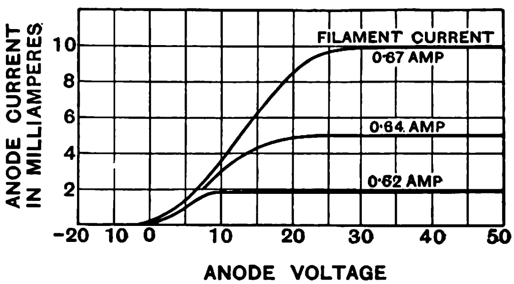


Fig. 1.

First, take a small two-electrode valve, which may be regarded as a modern edition of the original Fleming valve; it has an anode of nickel sheet 25 mm. long and 4 mm. diameter; mounted axially inside it is a tungsten filament 30 mm. long by 0.06 mm. diameter. The whole is mounted in a glass bulb and exhausted to the obtainable degree of vacuum.

Some characteristic curves of this rectifier are shown in Fig. 1.

The lower curve shows the anode current with 0.62 amp filament current and varying anode voltage (the anode volts measured from the negative end of the filament). It will be seen that with negative volts on the anode there is no anode current, but that as soon as the anode becomes positive with respect to the filament an anode current appears increasing with anode volts up to a limit of 2mA, after which increase of anode volts causes practically no increase. With larger filament current 0.64 and 0.67 amp, the curves are of the same general form, but the limiting value of anode current increases with filament current.

There are three main points to be considered in connection with these curves :—

1. There is no anode current with negative anode volts. This is because the only carriers of electricity available are the electrons which are emitted by the hot tungsten cathode—when there is a positive voltage on the anode they move over to it, but when there is a negative voltage on the anode they are forced back again into the filament.

2. There is a limit to the anode current at any definite filament current. It has been established on sound theoretical and experimental basis that the number of electrons emitted per second from a clean metal surface at a definite temperature is a definite physical property of the metal; it can be put in the form :

$$i = a\sqrt{T}e^{-\frac{b}{T}}$$

where i is the current emitted per unit area, T is the absolute temperature and a and b are physical constants of the metal. It will be seen from the form of

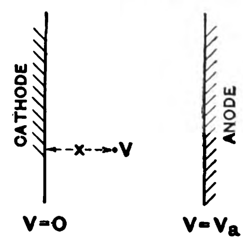


Fig. 2.

this expression that the emission increases very rapidly with T.

3. The third, and perhaps most interesting point, is that to obtain the full emission current a very appreciable positive voltage has to be applied to the anode—for example, returning to Fig. 1, it will be seen that with 0.67 filament current it is

necessary to apply 30 volts in order to obtain an anode current equal to the saturated emission. It might at first be thought that since we are dealing with negatively charged bodies the slightest positive voltage on the anode would cause every electron emitted from the filament to pass over to the anode. The explanation, however, is that the electrons on their way tend to repel those following on.

The following approximate treatment is due to Langmuir.* Consider a simple case in which the cathode and anode are parallel planes a distance d apart, as shown in Fig. 2.

Let V be the voltage at any point distance x from the cathode, V being zero at the cathode and equal to V_a at the anode. Let the number of electrons per sq. cm. per second passing from cathode to anode be n. Then the current per sq. cm. will be given by $I = ne$, where e is the charge of an electron, and we are taking that I is less than the total emission. If we assume that an electron leaves the cathode with negligible velocity, then when it has got a distance x from the cathode it has reached a velocity and will have gained kinetic energy by an amount equal to $\frac{1}{2} mv^2$ where m is the mass of an electron. It will, however, have lost potential energy by an amount V_e and on equating the two, $\frac{1}{2} mv^2 = V_e$.

At the point x, therefore, there are n electrons passing per second per sq. cm. with a velocity v. There will therefore be electrons at the rate of n/v per unit volume at this point, and therefore there will be a volume electrification of $-ne/v$ per unit volume. This is termed the Space Charge.

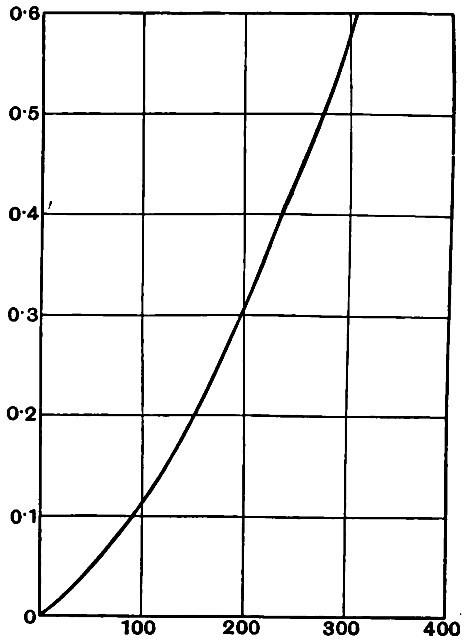


Fig. 4.

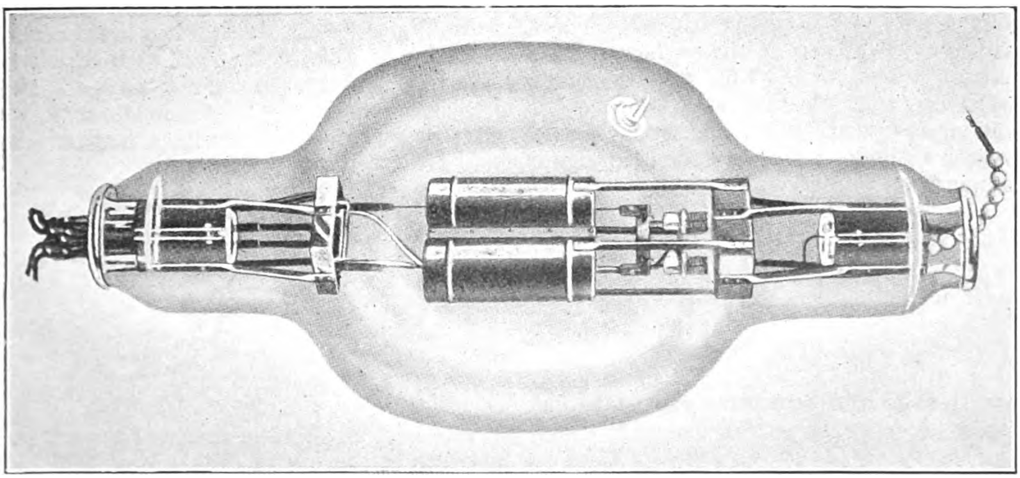


Fig. 3.

* Langmuir. *Physical Review*, 1916.

We can apply Poisson's equation and obtain

$$\frac{\partial^2 V}{\partial x^2} = -4\pi\rho$$
$$= .4\pi\frac{ne}{v}$$
$$= \frac{4\pi L}{V}$$
$$= 2\pi i\sqrt{\frac{2m}{eV}}$$

per cm. length of the rectifier is given by

$$i = 2.92 \times 10^{-5}\,\frac{V^{\frac{3}{2}}}{\beta^2 d} \quad \ldots \quad (2)$$

where β^2 is complicated function of the ratio of cathode and anode diameters, which, however, in most cases is sufficiently near unity to be neglected. This last equation is one of the most important in the whole subject and can be used for actual numerical design—an example will be given later.

The above treatment is, however, only

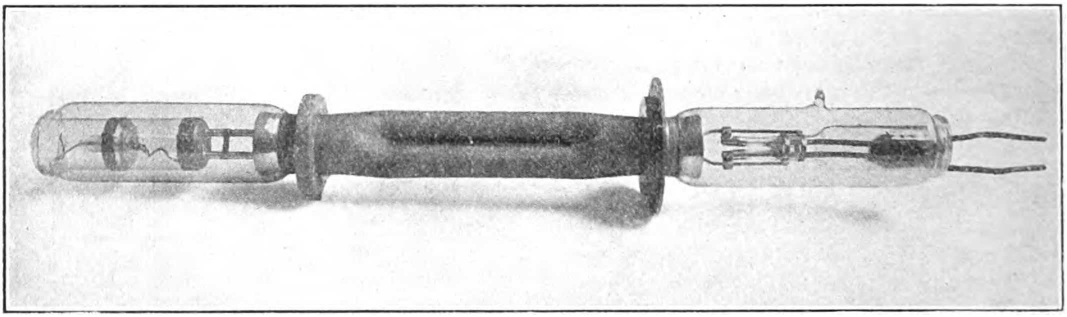


Fig. 5.

We can integrate this equation, obtaining

$$\left(\frac{\partial V}{\partial x}\right)^2 = 8\pi i$$

if we take $\partial V/\partial x = 0$ at the surface. This is fairly obvious, for if $\partial V/\partial x$ were negative no electrons would leave the cathode, and if $\partial V/\partial x$ were positive all electrons would leave the cathode. This equation can again be integrated, giving

$$L = \frac{\sqrt{2}}{9\pi}\quad\sqrt{\frac{e}{m}}\cdot\frac{V^{\frac{3}{2}}}{x^2}$$

and thus

$$i = \frac{\sqrt{2}}{9\pi}\cdot\sqrt{\frac{e}{m}}\cdot\frac{V_a^{\frac{3}{2}}}{d^2}$$

if amps, volts and centimetres are taken it becomes

$$L = 2.33 \times 10^{-5}\,\frac{V_a^{\frac{3}{2}}}{d^2} \quad \ldots \quad (1)$$

A far more important case is that of the cylindrical rectifier which has also been treated by Langmuir. Without going into details, if d is the anode diameter and d_c the cathode diameter, then the anode current

approximate. A more exact but much more complicated treatment has been given by T. C. Fry,* in which the distribution of initial velocities has been taken into account.

Owing to this high speed with which the electrons strike the anode and to their possessing mass they heat it in the same way that a bar of metal becomes heated when

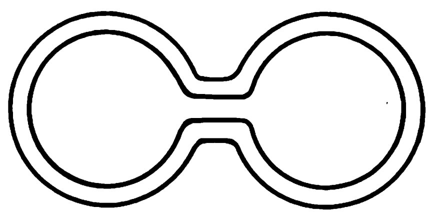


Fig. 6.

hammered, the kinetic energy $\frac{1}{2}mv^2$ of each electron appearing in the form of heat.

From the formulæ given it will be seen that the rate at which energy is liberated at the anode in the form of heat is equal to the product of anode volts and anode current.

* *Physical Review*, Vol. 17, p. 44.

Experiment.

Here the anode of a large glass rectifier of the MR9 type was bombarded to a bright red heat from a 4,000 volt transformer.

To simplify things to-night, only cylindrical type rectifiers and valves will be considered. Although many types of flat valves are on

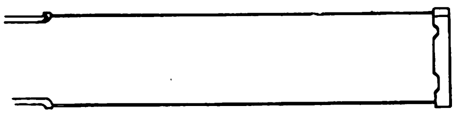


Fig. 7.

the market the adoption of this form is a concession to manufacturing simplicity and mechanical robustness—were the same length of filament mounted in a cylindrical grid and anode a definite improvement would be obtained.

The cylindrical type is not only best form electrically but has the advantage that it is amenable to calculation. In setting about the design of a rectifier the first point to be settled is the emission current required from the filament. From the known physical constants of tungsten* it is possible to design a number of alternative filaments of various temperatures, lengths and diameters

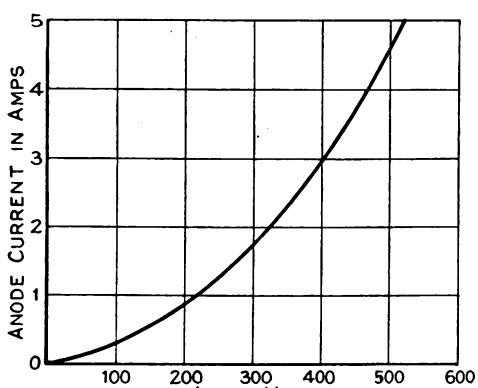


Fig. 8.

that will give the required emission from which a suitable filament can be chosen.

The two-electrode rectifier shown in Fig. 3 is an example of a large cylindrical type having two parallel filaments connected in series each in its own cylindrical portion of the anode which is of molybdenum; the filament takes 25 amps at about 20 volts and has an emission of about $1\frac{1}{2}$ amps. This represents almost the largest size made in a glass envelope; a characteristic is shown in Fig. 4.

A larger type of rectifier, having an external water-cooled anode, is the CAR2, shown in Fig. 5 without its water-jacket. The anode is made of one piece of copper tube, of which the central portion is pressed in as shown in Fig. 6 so as to consist of two parallel cylindrical portions.

The filament consists of two parallel portions, as in Fig. 7, each 20 cms. long by

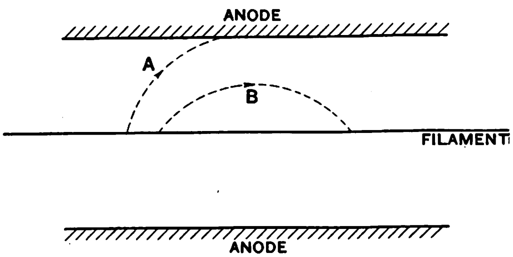


Fig. 9.

1 mm. diameter connected by molybdenum cross piece. The filament takes 50 amps at 20 volts, giving an emission of 7 amps and in assembly is slid into the anode so that one leg of the filament lies axially in each chamber of the anode.

An observed characteristic curve is shown in Fig. 8.

I will recall now equation No. 2 for the cylindrical valve. As pointed out, this valve has each filament in a cylinder. The characteristic was calculated from this equation before the valve was actually made. One of the calculated points was 500 volts, giving 4.75 amps, and you will see on the observed curve that it is actually very near to 4.75 amps. The rectifier characteristic came out to its calculated value certainly within 5 per cent. I mention this to show that the formulæ given are really of practical value.

In the making of these larger rectifiers we get no trouble until we get up to this size—of course, there is all the glass work, and the pumping of the valve is difficult, but no new physical effect appears. When we try to make bigger ones difficulties occur at

* Langmuir, *Physical Review*, 1916, Vol. 7, p. 302.
Stead, *J.I.E.E.*, 1920, p. 107.
Worthing, *Jour. Franklin Inst.*, Vol. 194, p. 597.

several points. For instance, suppose we want to increase the emission. In order to do that we have to increase the area of the filament, and we can do that in two ways, either by increasing its length or by increasing its diameter. If we decide to increase the length we run into a difficulty.

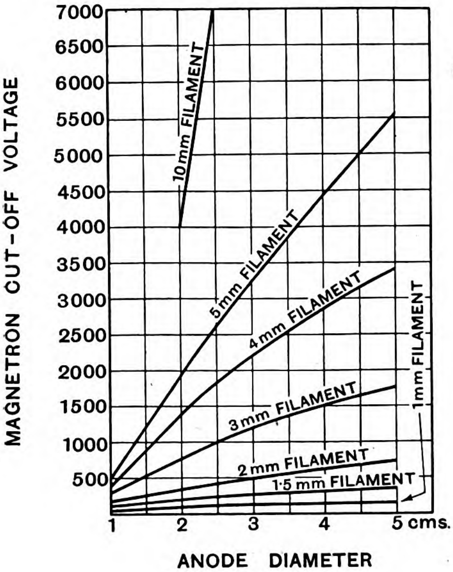


Fig. 10.

When taking anode current from a rectifier the electrons which flow from the filament to the anode have to be replaced by electrons which flow in at the negative end of the filament. That means that if you have a filament normally taking 10 amps, and it is so long that its emission is 10 amps, then at the negative end there is a current of 20 amps, which overheats that end of the filament.

This is shown by this small valve which has a very long fine filament with an emission equal to the normal heating current; the anode is in the form of a grid so that the filament is readily visible. When the H.T. is switched on it is seen that the negative end of the filament is overheated almost to the melting point.

The first limitation, then, is that we cannot lengthen our filaments indefinitely. If we are going to use the same diameter of filament we have to divide the filament into a number of sections, in parallel, but, although that can be done, it is not a very satisfactory arrangement from the manufacturing point of view if carried too far; all the filaments have to be so very well matched.

The other alternative is to increase the diameter of the filament, but there again we run into trouble.

Fig. 9 represents the section of a cylindrical valve, and shows the filament and the anode. The filament heating current has a magnetic field—the lines of force are in the form of circles around the filament. Now a property of an electron in motion is that it tries to bend round lines of magnetic force. In Fig. 9 lines of force are vertical to the plane of the paper, so that the electron, starting from the filament, is deflected round as shown at *A*. With a small filament the effect may be quite negligible, but if we put in a still larger filament, the electrons turn round and come back to the filament without getting to the anode at all, as shown in *B*.

Fig. 10 shows the extent of that effect. For any anode diameter and any diameter of tungsten filament there is a definite cut-off voltage*; if the anode voltage is below that, no electrons whatever can get

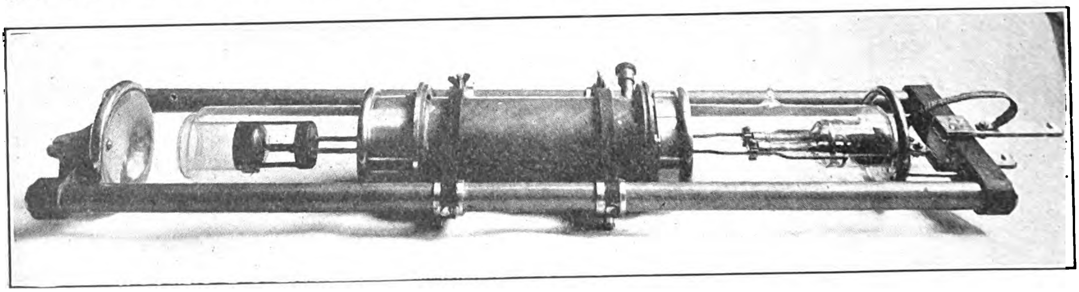


Fig. 11.

* Hull, *Journ. Amer. I.E.E.*, October, 1923, p. 1013.

to the anode. To take an example: If we have an anode of 3 cm. diameter, with a 1 mm. filament this voltage is about 100 volts; but if we put a 4 mm. filament in the same anode the cut-off voltage becomes over 2,000 volts, and that is so serious that the rectifier would be of very little use in practice; if, further, we go to 10 mm.

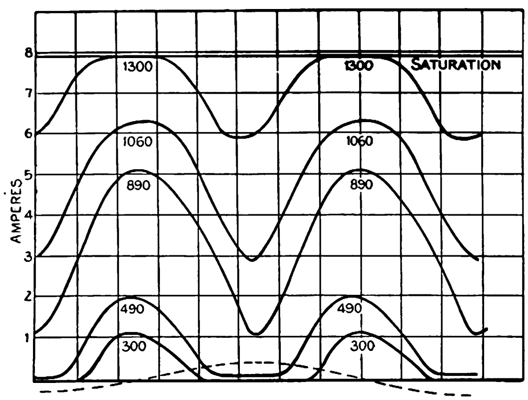


Fig. 12.

filaments, the voltage would get up to 6,000, which makes the use of the rectifier quite impossible.

Fig. 11 shows an example of a valve considerably larger than the previous one, but of the same general design, and in which this effect occurs to a marked extent. It has a filament of about 1.8 mm. diameter and its heating current is about 125 amps; the photograph shows the valve mounted complete with water jacket.

Fig. 12 shows some oscillograms taken of the anode current of this valve with a number of steady D.C. voltages on the anode while the filament was heated by 125 amps A.C.; the small dotted sine curve is the filament current on a reduced scale.

It will be seen that with 300 volts on the anode the anode current is entirely cut off for a large part of the filament current cycle and that even with 1,300 volts on the anode the filament current when passing through its maximum value can appreciably decrease the anode current. Owing to the fact that the anode current depends on the filament current there are a large number of characteristics of this rectifier.

Two of them are shown in Fig. 13; the full line shows the characteristic at the instant of zero filament current—the dotted line at the instant of maximum filament current of

$$125 \times \sqrt{2} = 177 \text{ amps.}$$

That shows that we have, more or less, got up to the limit. The only other possible way is to use numbers of filaments of 50 amps size and perhaps a little bigger connected in parallel.

As we are limited on the filament current types, an alternative method is that of the indirectly-heated cathode.

Fig. 14 is a sketch of two valves which I have here. One valve has a cylindrical anode, with a straight tungsten filament—quite an ordinary valve; the other has an anode of equal size, but, instead of a filament, it has for a cathode a nickel cylinder, which is coated with barium and strontium oxides. It is heated to about 800° C. by thermal radiation from a heavy 40-watt tungsten spiral filament—represented by the wavy line.

Up to the present such a valve is not made in large sizes, because a cathode which will stand high voltages satisfactorily is not at present known. However, this introduces a

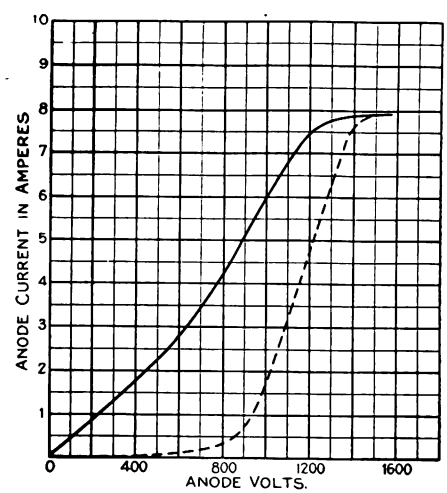


Fig. 13.

very interesting point in the design of valves.

I have mentioned the equation:—

$$I = K \frac{V^{\frac{3}{2}}}{\beta^2 d}$$

where V is the anode volts, and β the anode diameter and have mentioned that β^2

depends on the ratio of anode diameter to cathode diameter.

Fig. 15 shows the value of β^2 plotted against the ratio of anode radius over filament or cathode radius. In all ordinary filament valves this ratio is certainly more than 10, and for most purposes β^2 is near enough to unity, but when we get down to low values, when the ratio of anode to cathode is only slightly greater than unity β^2 becomes very small, which means for the same anode volts a great increase of anode current. In this valve the ratio is about 1.15, and β^2 is about 0.017, so that, since these valves have the same anode and about the same length of cathode, we should expect that the indirectly-heated cathode

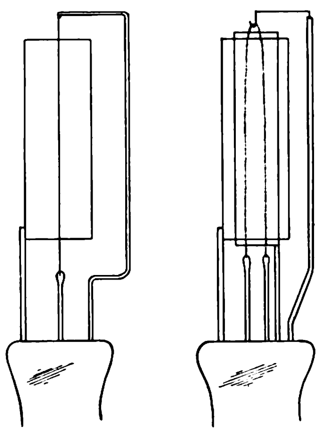


Fig. 14.

valve would give us 1/0.017, which is about 60 times the same anode current as the filament type; and that is so.

Fig. 16 shows the characteristic of these two rectifiers—anode volts against anode current; the lower curve is the filament rectifier, so small that it can hardly be put on the same scale, and the upper curve is the indirectly-heated cathode rectifier. We are getting 0.5 amp at 24 volts, which is quite unheard of in any ordinary rectifier, and the ratio of 60 to 1 for the two valves is attained. Unfortunately, up to the present, this principle has not been applied to very large valves.

So far I have been speaking chiefly about two-electrode valves. Not only the theory, but the actual numerical design, of the two-electrode valve is perfectly well established, and the next step is the consideration of anode current control. The usual form of control is the grid control; there is another form, which is not much used, although it is extremely interesting, and that is magnetic control. It has already been pointed out

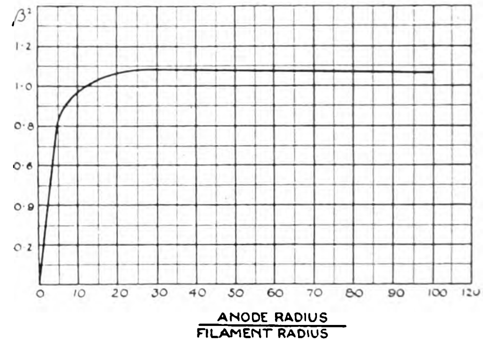


FIG. 186.—Values of β^2.

Fig. 15.

that the field due to the filament current has an effect upon the paths of the electrons.

Take a cylindrical valve as shown in section in Fig. 17 and surround it by a cylindrical coil and suppose that its filament is so small that the magnetic field of the

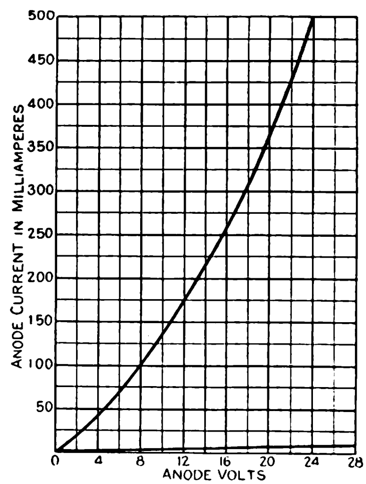


Fig. 16.

filament is negligible; then an electron leaving the filament will go straight to the anode as shown by the dotted lines A. If now a current is passed through the coil a magnetic field is set up of which the lines of force are parallel to the filament. With a

small current the electrons will be deflected, as shown by the dotted line B, while with still larger currents the electron may be turned completely round as shown by the dotted line C, in which case, of course, there is no anode current. The magnetic field

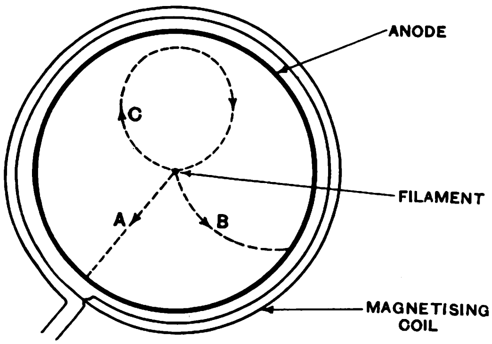


Fig. 17.

necessary to cause the electrons just to miss the anode is given by

$$H = \frac{6.72\sqrt{V}}{R}$$

where R is the anode radius.*

Fig. 18 shows the curves from a small valve at anode voltages of 40, 30, 20 and 10 volts. The sloping parts of the curves can be used in exactly the same way as the curves of the ordinary three-electrode valve, a steady current being used in an analogous way to a grid bias battery to bring the anode current to the centre part of its operating characteristic while on it can be superposed any A.C. current.

The practical drawback to this method of control is the large number of ampere turns required which make a large heavy coil with currents of the order of an ampere necessary for even small anode voltages.

We will now go back to the three-electrode valve. I have already pointed out that, as regards the simple two-electrode valve, we can design to an accuracy equal to that obtained in any ordinary engineering calculation. From this it is possible to go over to the three-electrode valve, and I will now deal briefly with the principles of that valve, showing how its theory can be derived from the two-electrode valve.

The left-hand side of Fig. 19 represents a section of a cylindrical three-electrode valve, the dotted lines showing roughly the lines of force when voltages V and v are applied to the anode and grid. It follows from previous results that the space charge due to the electrons traversing the space between filament and anode, is inversely proportional to the velocity of the electrons and is small between grid and anode where the electrons are moving quickly. Consequently the field of force, except in the immediate neighbourhood of the filament, can be treated approximately as a simple electrostatic problem. It can be shown that if a companion rectifier is made, such as is shown in the right-hand side of Fig. 19, having its anode equal in diameter to the grid diameter of the three-electrode valve and if to anode a voltage

$$\left(\frac{V}{m} + v\right)$$

where "m" is the amplification factor of the valve, is applied, then the field inside the anode of this valve is approximately the same as inside the grid of the three-electrode valve.

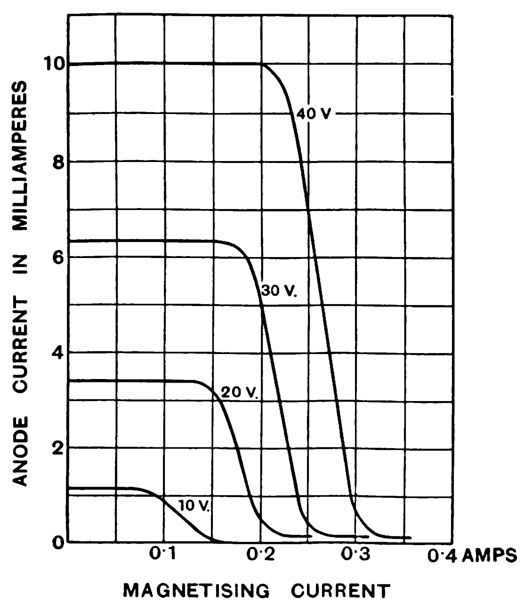


Fig. 18.

The amplification factor "m" of the valve can be calculated by the following approximate formula due to Sir J. J. Thomson.

$$m = \frac{\pi d' n \log \frac{d_a}{d'}}{\log 1/\pi n d_g}$$

* Hull, *J.A.E.E.*, September, 1921.

where n is the number of turns per cm. in the grid

d_a is the anode diameter.
d' is the grid diameter.
d_g is the grid wire diameter.

Since in the two valves the field in the neighbourhood of the filament is the same the space currents will be the same.

Hence, using the ordinary formula for a two-electrode valve, we have the space current of a three-electrode valve per unit length given by

$$I = 2.92 \times 10^{-5} \frac{\left(\frac{V}{m} + v\right)^{\frac{3}{2}}}{d'\beta^2}$$

If v the grid voltage is negative all the space current goes to the anode and the above formula then gives the anode current. Thus the design of the cylindrical three-electrode valve is on a firm theoretical basis.

Fig. 20 shows the characteristic of a valve having an m value of about 7; for if V and v are changed so that the anode current does not change, then

$$\frac{V}{m} + v$$

must remain constant, so that any change in v must be accompanied by a corresponding change "m" times as large in the opposite direction in V. Thus for this particular valve anode current of 15mA is obtained with V—80

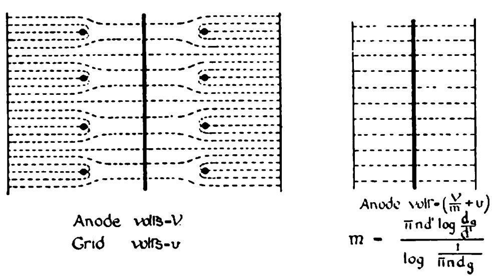


Fig. 19.

and v = —3, also the same anode current is obtained with V = 100 and v = —6, so that if V is increased by 20 volts v has to be decreased by 3 volts.

Hence for this valve "m"=20/3=7 approximately.

This account of some of the principles of the design of thermionic valves has necessarily had to be very brief and many points have had to be omitted altogether, but my chief endeavour has been to show that the design of thermionic valves is developing into an

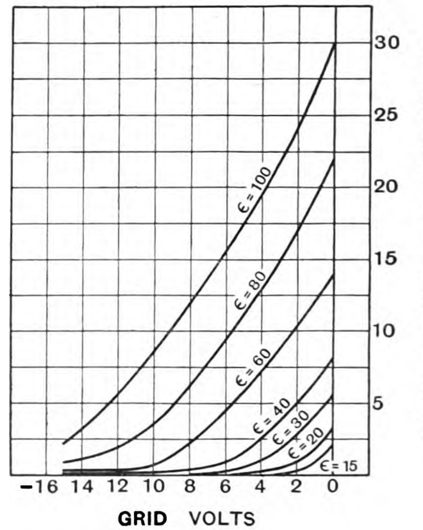


Fig. 20.

important branch of electrical engineering and in many ways has already been reduced to as accurate a numerical basis as most other branches.

DISCUSSION.

Mr. M. Kirk: I was particularly interested in the indirectly-heated cathode valves, because I think it is a very important thing, in the working of small receiving sets, to be able to light the valves directly off A.C. mains. I have tried one or two of the indirectly-heated cathode valves, and they are very efficient as regards the ratio of magnification to plate resistance, but we have a certain amount of trouble because they lose their emission. It seems that in nearly all new types of valves the first trouble is that they lose their emission. This trouble is usually rectified after the valves have been on the market for some time. I should like Mr. Bartlett to say something about loss of emission and its cause. Apparently it is not due entirely to the actual value of anode current, but it is largely due to the actual anode voltage, irrespective of the amount of anode current. There is another point I should like to raise. Mr. Bartlett did not mention the effect of the difference of potential across the filament of the valve on the characteristics of the valve. This effect, I believe, is very interesting, particularly on the curved portion of the bottom of the valve characteristic, and, as this portion is used largely nowadays for rectifying purposes, it is very important to get that curved portion as sharp as possible. I should like to know what hope there is of getting valves with a sharper curved portion. I have noticed particularly that in the separately heated cathode valves it is considerably

sharper than in the ordinary valves, and there is no difference of potential across the filament.

Mr. W. K. Alford: I also have been most interested in Mr. Bartlett's excellent lecture. I am glad Mr. Kirk has raised the question of the indirectly-heated cathode valve. I have done a considerable amount of work with these valves lately, and the first thing I did with one of them was to give it a life test. It lasted five days. The circuit on which the valve was put allowed it to draw an anode current of 4 milliamps continuously. After four days the emission of the valve had fallen off so that the anode current dropped to below 3 milliamps. I do not say that that is very serious, but the test gives a fair indication of its use in a broadcast receiver. It is interesting to note that another of these valves, which had evidently been produced at the factory about a month later than the other one, when tested under the same conditions, had not dropped its emission at all after a similar test. I tried one in the West of London, where there is a curious alternating current supply, with a periodicity, I think, of 83 cycles per second. The indirectly-heated cathode valve on that supply is indistinguishable from an ordinary type of valve with accumulator-heated cathode. If one takes the indirectly-heated cathode valve to a supply with a more usual periodicity, say 50 cycles, there is quite a distinct amount of residual hum left in the reproduction. The amount of hum, although hardly audible on an unmodulated carrier wave, is sufficient to break bottom frequencies distinctly and I should like Mr. Bartlett's observations in this connection.

Captain H. de A. Donisthorpe: In connection with the magnetron, it will be interesting to learn whether Mr. Bartlett has carried out any experiments with this device when the valve used is a soft one. In about 1921 I carried out some experiments with magnetic fields around thermionic valves, and found some very interesting differences between soft and hard valves. With a hard valve the effect was a dropping off of the anode current, but with a soft valve there was an increase for certain values of the magnetic field as against a valve operating under normal conditions.

The President (Brig.-General Sir Capel Holden): Mr. Bartlett hinted that there was some difficulty about making the indirectly-heated cathode valves in larger sizes. Is that a mechanical difficulty, is it simply that there would be trouble due to the extraordinary amount of heat in the valve, or is it that the manufacturers have not progressed sufficiently far with this particular type of valve to enable them to say exactly what would happen ?

Mr. Bartlett, replying to the discussion, said: One of the most important things I have to do is to answer for the faults of the indirectly-heated cathode valve. I think that possibly some of the earlier products were not quite so good as can be obtained now, but that is often the case. Mr. Kirk mentioned that the plate resistance is low. That is wrapped up entirely in the effect which is shown in the two valves of Fig. 14. In the indirectly-heated cathode valve the ratio of the cathode diameter to the grid diameter is much nearer unity than is the case in a filament valve, so that, although this valve has a very short, stumpy cathode, its characteristics are extremely good. The β^2 comes in the bottom of the equation. Mr. Kirk also mentioned the curved bottom of the valve, but I will deal with that later, as it is connected with the point raised by Mr. Henderson. Mr. Alford mentioned residual hum, and I must say that I am surprised that he obtained good results on an 83-cycle supply, but not very good results on a 50-cycle supply. Our experience is that a periodicity of 50 cycles is usually quite satisfactory, and anything higher—83 or 133—is apt to give hum.

The question of the lack of voltage drop across the cathode is very important and is shown up in a remarkable way by indirectly-heated cathode valves. Thus in an ordinary high "m" valve—take for example the DE5B, the effect is very noticeable; the characteristic curves instead of being simply displaced to the left by increasing anode volts as shown in Fig. 20 spread out from a point and it is impossible to get a definite figure for the "m" value in the usual way.

This is due to the fact that with small anode currents in a high "m" valve—often only a small fraction of the filament length is actually being used. Thus consider a valve having 100 volts on the anode, grid bias of 1 volt and an m of 40.

At the negative end of the filament

$$\frac{V}{m} + v$$

is thus equal to

$$\left(\frac{100}{40} - 1\right) = 1.5\,;$$

at a point along the filament 1 volt above the negative end the effective anode volts is 99 and the grid is —2 volts below this point on the filament; hence here

$$\left(\frac{V}{m} + v\right) = \left(\frac{99}{40} - 2\right) = .5 \text{ approx.}$$

But at a point 2 volts above the negative end

$$\left(\frac{V}{m} + v\right)$$

is a negative and there is no anode current from this point of the filament or any point at higher voltage.

Some experimental valves similar to the KL1 but with higher "m," which I believe are not yet on the market, show an accurate lateral displacement of characteristic together with a very low impedance such as cannot be approached by a filament valve.

The increase of anode current in a soft valve when a magnetic field is applied, mentioned by Captain Donisthorpe, is doubtless explained by the increased ionisation of the gas due to the longer curved paths of the electrons; the extra positive ions decrease the Space Charge effect and give a larger anode current.

In answer to the President there would probably be little difficulty in making larger size indirectly-heated cathode valves for fairly low voltages—the difficulty is to get coatings which will run satisfactorily with higher anode voltages.

Abstracts and References.

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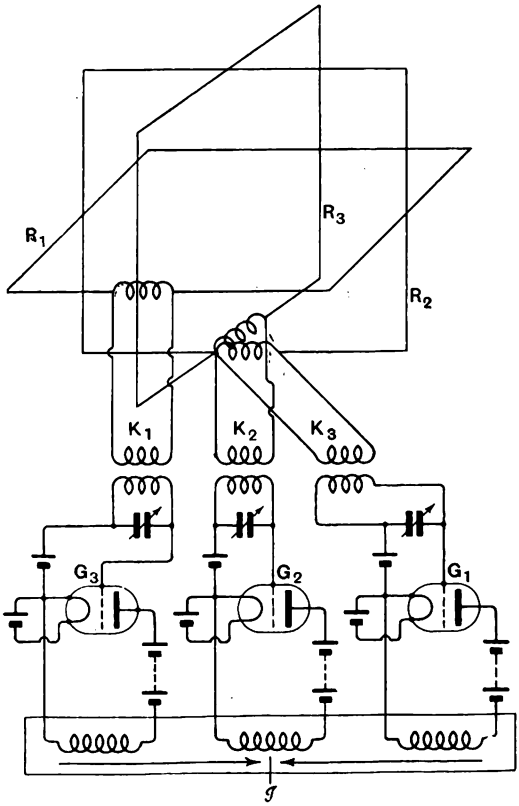
PROPAGATION OF WAVES.

UNGERICHTETEN EMPFANG (Undirectional reception) —N. v. Korshenewsky. (*Zeitschr. f. Hochfrequenz*, 29, 3, March, 1927, pp. 78-80.)

It is shown mathematically that, with appropriate orientation of the incoming radiation field and receiving antenna, the frame and the linear antenna are equivalent as concerns directional reception, and that there are no undirectional antennæ.

For wireless short wave reception, however, a nondirectional means of receiving is required, that



is independent of the angle of incidence of the arriving waves and their state of polarisation, since the continual changes in the direction of polarisation and angle of incidence of the incoming waves can cause marked variation of the signals being transmitted.

The alterations of the direction of polarisation are attributed principally to the unhomogeneousness of the atmospheric layers and the action of the earth's magnetic field. The causes for the alteration of the angle of incidence are naturally also to be looked for in the changing condition of the atmospheric layers, largely in the variation of the electronic density of the Heaviside layer in a vertical direction: according as to whether the density of the electrons becomes greater or less with the height, the electro-magnetic wave undergoes greater or less bending. The continual fluctuation of the ionic density is thus responsible for the variation of the angle of incidence of the ray arriving at the receiver as a result of atmospheric refraction. For the ray arriving after reflection at surfaces of different refracting power, the angle of incidence changes with alteration in the height or inclination of the reflecting layer, which alteration is always taking place. Thus whether the ray arrives after refraction or reflection, its inclination to the earth's surface must be continually changing, producing corresponding variations in the antenna current, quite independently of which type of aerial is employed. These variations of the intensity received can produce serious distortion in the transmission of speech or music also, particularly in picture telegraphy.

The necessity therefore arises for the production of a receiving system that will eliminate unintentional variations in the intensity received. Such a system is shown to be obtained by means of three equal aerials (either linear or frame) at right angles to one another, whose oscillations affect a common indicating instrument after passing through separate rectifiers. The figure opposite shows how three frame antennæ are arranged for undirectional reception.

The frames R_1, R_2 and R_3 are connected through the leads K_1, K_2 and K_3 to the rectifiers G_1, G_2 and G_3, the anode circuits of which act on a common instrument $\mathcal{J}$, whose indications are independent of the angle of incidence and direction of polarisation of the incoming wave.

EXPÉRIENCES SUR LA PROPAGATION DES ONDES COURTES (Experiments on the propagation of short waves).—A. Colmant. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 82-91.)

Lecture given to the Société des Amis de la T.S.F., 16th January, 1926, describing the continuation of the tests between Paris and Algiers made during 1924 (*L'Onde Electrique*, January, 1925).

From the results, which are tabulated and discussed in detail, it is concluded that it is not possible definitely to enunciate hypotheses on propagation, owing to the sudden occurrence of peculiar unexpected facts that do not fit in with the law which otherwise appeared to be satisfactory, also because secondary causes doubtless enter in that mask the true laws of propagation.

The principal difficulty met with in this investigation is expressed as follows: the flat-top of a transmitting antenna can no longer be regarded

as a simple capacity with short waves, but behaves like a horizontal antenna ; in what proportion is the energy divided between the flat-top and the vertical wire and how does it vary with the wavelength ? Also what is the relation between the energy of the space wave and that of the ground wave ?

A second difficulty is stated to be the impossibility of separating the direct from the indirect wave in the majority of cases. Complete absorption of the ground wave was only found for waves of the order of 25 metres, and nothing definite could be arrived at for waves of 50 metres or longer.

The experiments, however, appear to confirm the opinion previously formed that the trajectory of a ray resulting from successive refractions in upper strata is *unsymmetrical* with reference to the perpendicular erected midway between the point of departure of the ray and its point of arrival.

Short Wave Receiving Tests across the Pacific.—T. Nakagami. (*Journ. Inst. Elect. Eng., Japan*, March, 1927, pp. 249-255.)

The transmission from KEL, Bolinas, California, U.S.A., on a wavelength of 29.3 metres, was received at Iwatsuki on 21st October, 1926, for 24 hours. The audibility curve and recording tape are reproduced showing the conditions under which reception took place at different hours. The signals were strong and steady throughout the tests and could be received for 19 hours any day and easily recorded at moderately high speeds after dark. The transmitter worked on the power amplifier system exciting a non-directional aerial with the rated output of 20kW, and the receiver consisted of an autodyne detector, six-stage audio amplifier and rectifier.

Discussion on Radio Broadcast Coverage of City Areas (Espenschied).—(*Journ.A.I.E.E.*, April, 1927, pp. 377-378.)

Discussion of the paper that appeared in *Journ. A.I.E.E.* for January, 1927, p. 25.

Les Limites de ma Théorie de Propagation (The limits of my theory of propagation).—F. Kiebitz. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 127-131.)

In *L'Onde Electrique* for December, 1926 (these abstracts *E.W. & W.E.*, March, 1927, p. 175), Mesny expresses his disagreement with Kiebitz's new propagation formula (*Ann. d. Phys.* 80, 1926, 728; these abstracts, January, 1927, p. 49). In the present note Kiebitz replies to Mesny's objection by showing that it refers to terms inversely proportional, not to the distance for which his solution is strict, but the second power of the distance—terms which are neglected in his theory.

A reply from Mesny follows, indicating that even with the order of approximation adopted, Kiebitz's formula cannot represent the law of wave propagation around the earth.

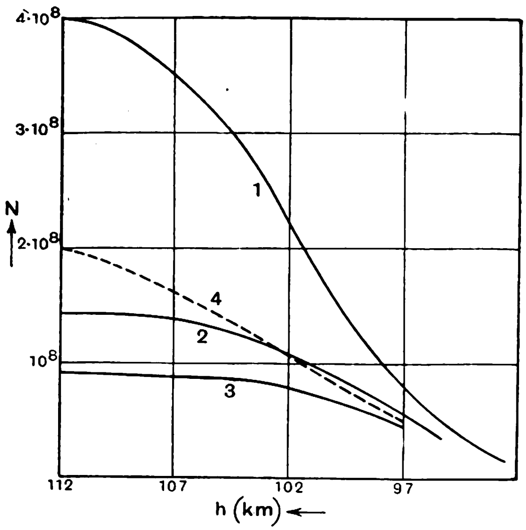
On the Radio Field Intensity of Time Signals sent out by the Pearl Harbour Station, observed at Tokio.—T. Minohara. (*Journ. Inst. Elect. Eng., Japan*, No. 464, March, 1927, pp. 225-232.)

The results are given of a series of measurements made at the Naval Experimental and Research Establishment, Tokio, on the signals from Pearl Harbour, covering the period September, 1925, to October, 1926.

Comparing the variations of intensity observed with those of the atmospheric conditions including temperature, humidity and pressure, it is remarked that they are synchronous. The interesting fact is found that the variations are in the same sense during a certain interval and in the opposite sense during another interval, just as often happens with meteorological phenomena. It is observed that perhaps the distance 6,400 kilometres is too long to draw this conclusion, but that the results are very similar to Dr. Austin's made at a distance of 200 kilometres. The field intensity curves are shown and compared with those recorded simultaneously for the temperature, pressure and vapour tension of the atmosphere.

Die Täglichen Schwankungen des Ionisationszustandes der Heaviside-Schicht (Daily variations of the state of ionisation of the Heaviside layer).—H. Lassen. (*Elekt. Nachr, Technik*, 4, 4, April, 1927, pp. 174-179.)

From previous experiments with short waves (less than 1 kilometre) it is concluded that the



ionisation of the Heaviside layer by day is relatively constant, but that during the night the ionic concentration steadily decreases down to about the fourth or fifth part of the day value. This variation can be directly explained on the assumption that hydrogen ions and not free electrons are mainly operative. By day free electrons are also present, but their action on electric waves is unimportant compared with that of the ions. The ionising agent that is principally effective is the ultra violet light from the sun, the decrease in ionic concentration during the night being due to the reunion of positive and negative charges.

The preceding graph is given to show the concentration of the ions at different times of the day in relation to the height.

Curve 1 represents the number of ions in the daytime.
Curve 2 six hours after the sun has ceased to shine.
Curve 3 twelve hours after the sun has ceased to shine.
Curve 4 one hour after recommencement of sun's radiation.

ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY.

THE RANGE OF ATMOSPHERICS.—(*Nature*, 7th May, 1927, p. 689.)

Brief account of the report of the Committee on Atmospherics and Weather presented by Mr. Watson Watt at a meeting of the Royal Meteorological Society, on 20th March.

LIGHTNING SURVEY IN JAPAN.—R. Mitsuda. (*General Electric Review*, 30, 3, pp. 124-128.)

Report on the lightning strokes observed in Japan between 1921 and 1924, leading to the following conclusions :—

1. Lightning storms generally have definite courses of progress, depending on the local topographic and atmospheric conditions. They almost always originate in high mountainous regions and gradually descend to the flat fields along valleys.

2. More than 40 per cent. of the total lightning flashes occur in August and the least number in winter. This seasonal change resembles that of humidity and the temperature of the atmosphere.

3. Lightning occurs mostly in the evening, especially (40 per cent.) between 3 and 6, and almost never around midnight.

4. The nature of the soil has some bearing on the frequency of lightning strokes: moist, conductive soils seeming much more liable to lightning than dry soils.

MEASUREMENT OF SURGE VOLTAGES ON TRANSMISSION LINES DUE TO LIGHTNING.—E. Lee and C. Foust. (*General Electric Review*, 30, 3, March, 1927, pp. 135-145.)

In *Journal A.I.E.E.*, October, 1926, McEachron gives the results of a detailed study of the calibration of the photographic Lichtenberg figures using the Dufour Cathode Ray Oscillograph as a means for determining with certainty the wave shape of the impressed voltage. The present article contributes additional data and shows that voltages of the order of 2,000,000 volts may be recorded with a reasonable degree of accuracy.

AU SUJET DE L'AURORE DU 15 OCTOBRE OBSERVÉE EN NORVÈGE (On the subject of the aurora of 15th October observed in Norway).—H. Jelstrup. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 132-134.)

Description of this remarkable aurora, with the soft sibilant sound heard at the same time, whose very distinct modulation seemed to follow exactly the undulations of the aurora.

Further observations by Prof. Carl Störmer are appended.

ELECTRICITY OF DUST CLOUDS (PART I).—G. Deodhar. (*Proc. Physical Society*, 39, 3, April, 1927, pp. 243-249.)

In tropical regions like India, large volumes of dust are blown up into the atmosphere, causing what are called dust storms. Such storms produce a great increase in the potential gradient and are a considerable menace to the wireless operator.

The factors governing the phenomena of electricity of dust storms are given as follows: material of the dust, its size, the gas raising the cloud, its velocity, and the temperature. The present paper examines the first two factors.

It is concluded that the electrification is produced by friction, but that there is no definite rule regarding the nature of the electrification and the material of the dust, also that the voltage developed increases very rapidly as the size of the dust particles diminishes.

PROPERTIES OF CIRCUITS.

PERFECTIONNEMENTS AUX AMPLIFICATEURS À RÉSONANCE (Improvements in resonance amplifiers.)—Blanchard. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 57-70.)

Investigation of two circuit-arrangements for resonance amplifiers in which the amplification is approximately constant in a small band of frequencies and practically nil outside of this band. Thus, while these circuit arrangements are not filters, they have analogous properties which are very advantageous, particularly for the medium frequency amplifiers of superheterodynes for broadcast reception.

RESONANCE IN ALTERNATING CIRCUITS CONTAINING A SINGLE HARMONIC.—F. Miller. (*Physical Review*, 29, 4, April, 1927, pp. 546-553.)

The phenomenon of resonance in a circuit having impressed upon it a sinusoidal E.M.F. is a familiar one, and full discussions of it have been presented by many writers; but the current-frequency relations as affected by the presence of harmonics in the voltage wave, although often met with in practice, are not so well known. This paper investigates some of these relations for the case in which one harmonic, of order n, is present in the applied E.M.F. Methods of analysis are here merely outlined, and the conclusions arrived at stated.

DISCUSSION ON THE OUTPUT CHARACTERISTICS OF AMPLIFIER TUBES (Warner and Loughren).—E. Green. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, p. 319.)

Further discussion to that given in the March issue of the *Proceedings* on the paper that appeared in the December number of the *Proceedings* (these Abstracts *E.W. & W.E.*, March, 1927, p. 178.)

ÜBER SCHWINGUNGSKREISE, DIE DURCH EINE EISENKERNSPULE GEKOPPELT SIND (On oscillatory circuits coupled by means of an iron-cored coil). — H. Winter-Günther. (*Zeitschr. f. Hochfrequenz.*, 29, 4, April, 1927, pp. 103-114.)

The behaviour is studied, partly theoretically

and partly experimentally, of two oscillatory circuits coupled over a coil with a closed iron core. Distinction is made between the cases where primary and secondary circuits have the same natural frequency and where their natural frequencies are different.

(*a*) Where primary and secondary have the same natural frequency: theory shows and experiment confirms that in this case both free and forced oscillations are composed of two parts, one of which corresponds to the oscillations of an iron free condenser circuit while the other to those of a simple condenser circuit with an iron-cored coil.

(*b*) When the natural frequencies of primary and secondary are different: the investigation here extended only to the current tension characteristics of forced oscillations and was limited to cases of approximately sinusoidal currents.

The problem is treated as one of current division, the experiments yielding three essentially different types. The reactances of the primary and secondary circuits determine the characteristic curves, and not the inductances (as is sometimes assumed).

The characteristics are of special interest when the reactance of the secondary equals the maximum inductance of the iron cored coil. When the tension is continuously regulated in this case, sudden changes in the effective value of the primary current occur which are nearly as great as when there is no secondary. With a view to their applicability to the modulation of high frequency currents, these reversible tilting phenomena are studied in detail.

SLOPE INDUCTANCE.—C. Cosens. (*E.W. & W.E.*, June, 1927, pp. 331-335.)

A note on the effective inductance of iron-cored chokes or transformers.

SELF-INDUCTANCE OF STRAIGHT WIRES.—R. Wilmotte. (*E.W. & W.E.*, June, 1927, pp. 355-358.)

MODELLREGELN FÜR SCHWINGUNGSKREISE MIT EISENKERNSPULEN (Model rules for oscillatory circuits with iron-cored coils).—H. Winter-Günther. (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 81-82.)

It is often necessary to transfer the experimental results obtained with an oscillatory circuit with an iron-cored coil to circuits containing iron chokes of other dimensions. Model rules for this purpose are derived in this article. Mathematical investigation is made of :—

(*a*) Simple oscillatory circuits with iron-cored coils and direct current superimposed, and

(*b*) Oscillatory circuits coupled over an iron-cored coil.

ÜBER ANODENGLEICHRICHTUNG (On anode rectification. — M. von Ardenne (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 82-88.)

The value of the rectification, produced by the curvature of the anode current characteristic, is investigated in relation to the value and nature of the resistance in the anode circuit. From the viewpoint of practical requirement, particular attention is given to finding when the rectifying effect is specially large (for the construction of sensitive rectifiers) and under which conditions it is small (for the production of amplifiers free from distortion).

SUR LES AMPLIFICATEURS DE PUISSANCE SANS DISTORSION (On distortionless power amplifiers).—A. Clavier and I. Podliasky. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 71-81).

This subject has been treated already by various authors, in particular by B. W. Kellogg (*Journal A.I.E.E.*, May, 1925, and *L'Onde Electrique*, November, 1925). It is taken up again here from a different aspect with a view to bringing to light practical rules for a rapid pre-determination of the working conditions of these amplifiers.

A formula that can be easily applied is given for finding the apparent optimum resistance to introduce into the output circuit of the amplifier in the case where the power to be dissipated on the anode at the moment of static functioning is determined. A classification of amplifying triodes is shown and a means of calculating a modulator for a radiophonic transmitter.

SUR LA DÉTECTION PAR LAMPE (On valve detection). —P. David. (*Comptes Rendus*, 184, 25th April, 1927, pp. 1000-1002.)

When one attempts to go beyond the elementary and qualitative explanation of valve detection in order to analyse the phenomena and verify the theory experimentally, the author states it is only to find the literature on the subject incomplete and sometimes contradictory. The purpose of the present article is to take up the question again as a whole. The result of the mathematical investigation is given as follows :—

For every system the detection output begins to improve when the initial amplitude u_1 of the carrier wave or the local oscillation increases. Then this output becomes independent of u_1: the detection curve presents a rectilinear part in which the detected current is strictly proportional to the amplitude of the small variations Δu. This part must be systematically utilised in order to have maximum sensitivity and minimum distortion. The characteristics are tabulated of various French valves with the different detecting circuit arrangements employed.

Lastly, it is shown that in the normal superheterodyne, detection is not effected by the grid, as is believed and in spite of the presence of the shunted condenser, but by the curvature of the plate characteristic.

L'UTILISATION DES LAMPES À QUATRE ELECTRODES (Employment of four-electrode valves.)—B. Decaux. (*L'Onde Electrique*, 6, 61, January, 1927, pp. 1-18.)

A survey of the different uses to which four-electrode valves can be put. The object usually sought in introducing a fourth electrode is either greater sensitivity, or negative resistance, or a reduction of the plate tension, or a combination of these effects.

Under " Generalities," mention is made of Scott-Taggart's double-plate valve, the negatron, giving

rise to a circuit with negative resistance; also of Hull's pliodynatron, a development of his dynatron, with a perforated plate at a high potential and the ordinary plate at a lower potential, where negative resistance effects are obtained from secondary emission. The most useful four-electrode valve is said to be that with two grids, known in France as "bigrille," in which the interior grid serves as an "electron pump," the plate voltage by itself being in general too weak to produce a large enough electron current. The double-grid valves investigated by Barkhausen are based on a quite different principle: here the interior grid serves as grid, while the exterior grid is raised to a positive potential a little below that of the plate. Further, Marconi has employed valves in which the interior grid is used as grid and the exterior grid as plate, the plate itself being kept at a fixed potential.

The second section discusses arrangements with one grid which comprise two principal types corresponding to different purposes. In the one the question of simplicity is overlooked in order to have very high amplification, while in the other one is satisfied with normal amplification but has a very reduced plate battery.

The third section considers arrangements with two grids, nearly all of which operate with reduced plate voltage, discussing in particular valves of multiple function, balanced arrangements, and the utilisation of negative resistance.

TRANSMISSION.

SUR L'ENERGIE RAYONNÉE PAR LES RÉSEAUX ELECTROMAGNÉTIQUES (On the energy radiated by electromagnetic systems).—R. Mesny. (*Comptes Rendus*, 184, 2nd May, 1927, pp. 1047-1050.)

A mathematical discussion in which, in order to express the energy radiated in terms that can be easily handled, the parallel wires traversed by equal currents are replaced by a continuous sheet of metal, resulting in the drawing up of simple formulæ that can be applied to the systems employed in practice with little error.

The expressions obtained show that grouping several antennæ together considerably increases the radiation resistance of each of them taken separately. If, for example, two antennæ are a quarter of a wave apart, the resistance of each becomes multiplied by about 1.5. Physically, this increase is readily seen to be due to the component of the field of the neighbouring antennæ which, on a given antenna, is found in opposition with the current in this antenna (*Brillouin*, *Radio Electricité*, 3, p. 147, April, 1922).

EIN BEITRAG ZUR BERECHNUNG VON ERDVERLUSTEN BEI ANTENNENANLAGEN (Contribution to the calculation of earth losses with antenna systems.)—R. Mayer. (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 71-76.)

Of the total earth loss of large antenna systems for long waves, three kinds of loss are distinguished:—

1. When earth plate and counterpoise are absent and there is only an earth of very limited extent in the vicinity of the source of current, the loss then corresponds to a free alternating current in metal-free earth, the current density increasing towards the earth's surface.

2. When there is a buried metal earth, loss then occurs in the earth near the leads carrying the current over the earth to the current source.

3. Loss in the immediate neighbourhood of the metal earth (electrode or propagation loss), for which the corresponding direct current formulæ hold good with sufficient accuracy.

This paper considers mathematically the first two kinds of loss and formulæ are developed which are tested by the values found experimentally.

TÉLÉGRAPHIE ET TÉLÉPHONIE MULTIPLEX SUR ONDES COURTES (Multiplex telegraphy and telephony on short waves).—M. Veaux. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 120-126.)

Multiple modulation has been the object of certain applications, principally in the domain of telemechanics with a view to securing a certain amount of secrecy in the communications and protection against interference. This article recalls the principle of multiple modulation and shows its use on short waves for multiplex transmission in telegraphy and telephony.

UN CHANGEUR DE FRÉQUENCE À MONTAGE SYMÉTRIQUE ET À LAMPES BIGRILLES (A frequency changer with symmetrical circuit arrangement and four-electrode valves).—A. Cazes. (*Radio-Revue*, May, 1927, pp. 359-360.)

RECEPTION.

DISPOSITIF ATTÉNUANT LES EFFETS DU FADING (Device for mitigating fading effects).—H. de Bellescize. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 110-119.)

Lecture given to the S.A.T.S.F., 11th January, 1927, describing a device for continually adapting the sensitivity of the receiver to the intensity of the signals received by the antenna, so as to obtain faithful reproduction of the modulation and permit the operation of certain circuit arrangements requiring absolute steadiness in the carrier wave.

A PROPOS DES "FILTRES ACOUSTIQUES" (Concerning "acoustic filters").—P. David. (*L'Onde Electrique*, 6, 61, pp. 47-51.)

An article referring to M. Nodon's paper in *L'Onde Electrique* for last December, where the employment of acoustic filters is recommended to completely eliminate disturbances in radio telephony. The author details reasons for considering M. Nodon's optimism excessive and even that these filters are unable to improve radio telephone reception at all.

A "PRESS" RADIO RECEIVER.—(*Electrical Review*, 8th April, 1927, p. 574.)

Particulars are given of a new Marconi instrument guaranteed for aural reception of news bulletins from any long-wave C.W. station at the extreme limit of its range.

DIRECTIONAL WIRELESS.

A PORTABLE RADIO DIRECTION FINDER.—(*Journal of the A.I.E.E.*, February, 1927, p. 131.)

Mention is made of a paper by F. W. Dunmore, just issued by the Bureau of Standards, describing the development of a portable direction finder with but two controls—one for tuning and one for balancing. This direction finder operates over the frequency band from 90 to 7,700 kilocycles (3,300-39 metres). The direction finder is of the simple rotating coil type. The receiving set is of the superheterodyne type, with the controls reduced to one by the use of a cam-operated condenser. The wide frequency range is made possible by a set of seven interchangeable plug-in direction finder coils, each with a corresponding heterodyne generator coil and cam for operating the auxiliary tuning condensers.

This paper is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D.C., for 10 cents.

REMARQUE AU SUJET DES EMISSIONS HERTZIENNES DIRIGÉES (Note on the subject of directional Hertzian transmission). — A. Blondel. (*Comptes Rendus*, 184, 11th April, 1927, pp. 923-925.)

In a preceding article (*Comptes Rendus*, 184, p. 561, these Abstracts, *E.W. & W.E.*, June, 1927, p. 372) the author showed how two curtain antennæ can be excited by an oscillating inductor, alternately or simultaneously, giving emissions constantly opposed in phase. This arrangement is a particular case of the double curtain antenna system previously described and presents the two-fold advantage of an easier realisation of the double curtain and an uninterrupted modification of the alternating induction on each curtain, if all break in the circuits is avoided.

In the present note a further development is described in which the curtain antennæ are replaced by frames, enabling the alternate excitation of each frame to vary between a maximum and absolute zero, whatever the angle between the frames. The adjustment is such that there is no periodic variation of the phase of the exciting currents, but only periodic variation of their relative intensities: any phase displacement would give rise to a rotating field which would render its extinction impossible.

VALVES AND THERMIONICS.

CONTRIBUTION À L'ETUDE DE LA RÉPARTITION DES TEMPÉRATURES LE LONG D'UN FILAMENT INCANDESCENT DE TUNGSTÈNE CHAUFFÉ ELECTRIQUEMENT DANS LE VIDE (Contribution to the study of temperature distribution along a glowing tungsten filament heated electrically in vacuo).—G. Ribaud and S. Nikitine. (*Annales de Physique*, 7, pp. 5-34.)

Two corrections are applied to Worthing's theory of temperature distribution for a long filament, and the distribution in a short filament is investigated. A relation is found for calculating the central temperature of a short filament in terms of its linear dimensions and the current.

WIRELESS TRANSMITTING VALVES.—(*E.W. & W.E.*, June, 1927, pp. 359-367.)

Abstracts of three papers read at the meeting of the I.E.E. Wireless Section on 4th May, dealing respectively with the Holweck demountable type valve, silica valves in wireless telegraphy, and cooled-anode valves.

EQUATIONS FOR THERMIONIC EMISSION.—W. Ham. (*Physical Review*, 29, 4, April, 1927, p. 607.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

It has recently been shown that an equation of the form $i=A_{\varepsilon}^{-b_0/T}$ applies as well as any other to experimental data on thermionic and photo-electric emission. The paper discusses the derivation of this equation from Richardson's general equation.

A TYPE OF OSCILLATION HYSTERESIS.—L. Taylor. (*Physical Review*, 29, 4, April, 1927, p. 617.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927).

A simple triode oscillator was modified by placing a high resistance (.5—1.0 meg.) shunted by a capacity of 0.1μF in series with the grid. The circuit then oscillated intermittently, the period during which oscillation occurs being called a zule. Over a wide region the zule frequency F is found to obey a simple relation to the constants of the circuit, *i.e.*, $F=A\ exp\ [(L_2-kC_2)/2L_1]$, where A and k are constants. At the borders of these regions F is extremely sensitive to very small changes in L_2 and C_2. A theory is given for the formation of zules showing how they are related to the state of depression of the grid potential. Their finite length is due to a type of oscillation hysteresis, where oscillation ceases at one value of E_g and is resumed at a higher value. At the end of a zule, the mean of E_g is equal to the dynamic cut-off potential, and at the start of the next zule is several volts higher, increasing exponentally between these values. The variations of E_g were later studied by means of a synchronised oscilloscope, and all points of the theory were checked. Oscillation within the main circuit showed the same formation except that the potential between zules was constant.

ÜBER SCHALTVORGÄNGE BEI ELEKTRONENRÖHREN (On circuit phenomena with valves).—R. Mayer. (*Zeitschr. f. Hochfrequenz.*, 29, 3, March, 1927, pp. 76-78.)

Remark on the paper by Fischer and Pungs "Schnelltelegraphie mit Steuerdrosseln" (*Zeitschr. f. Hochfrequenz.*, 27, p. 51; these Abstracts, *E.W. & W.E.*, June, 1926, p. 385).

The course taken by anode and grid currents when the grid potential is suddenly altered, is shown with the aid of the series of characteristics "anode and grid currents as a function of the anode potential with different grid potentials."

GENERAL PHYSICAL ARTICLES.

PIEZO-ELECTRICITY OF CRYSTAL QUARTZ.—L. Dawson. (*Physical Review*, 29, 4, April, 1927, pp. 532-541.)

Description of an extensive investigation of the

piezo-electric effect in crystalline quartz, with the apparatus employed, and the results obtained.

Experimental measurements with the quadrant electrometer of the distribution of the piezo-electric charge over the surface of a quartz crystal in a plane normal to the optic axis were found to vary in such a manner as to produce six regions of charge, three positive areas alternating with three negative. The areas had definite geometrical relations to the electric axes and therefore these facts yielded a new and accurate method of determining the directions of the electric axes in crystal quartz. In planes containing the optic axis there was a region of positive charge separated by a line in the direction of the optic axis from a region of negative charge.

The piezo-electric effect increased by 20 per cent. from room temperature to 60 deg. C., and decreased thereafter, reaching zero at about 573 deg. C. Cooling curves showed a lag.

The piezo-electric charge produced on different specimens, or on different areas of the same specimen, all specimens being optically perfect, varied from large positive values of charge to large negative values. In general, the surface of the crystal quartz produced piezo-electric charges of the same sign, but of varying magnitudes. The charge measured over the entire surface of a crystal appeared to be the average of the effects of the elementary areas. The values found in these experiments with different specimens varied on the negative side of the crystal from 5.8×10^{-8} to 7.1×10^{-8} *e.s.u./cm*^{2} $\times$ dyne, and on the positive side from 4.9×10^{-8} to 6.4×10^{-8} *e.s.u./cm*^{2}, figures which do not differ widely from the accepted value of 6.3×10^{-8} *e.s.u./cm*^{2} $\times$ dyne, the "piezo-electric constant" of P. & J. Curie. Such variations are in keeping with recent X-ray investigations on the imperfections of crystals.

It appears that a complete theory of the piezo-electric effect, capable of coping successfully with all the phenomena now known, must await a more comprehensive understanding of the molecular structure of quartz.

PIEZO-ELECTRIC CRYSTALS AT RADIO FREQUENCIES.—A. Meissner. (*Proc. Inst. Radio Engineers*, April, 1927, pp. 281-296.)

Translation from manuscript received 11th October, 1926, presented at the meeting of the Institute of Radio Engineers, New York, 2nd March, 1927.

THEORY AND APPLICATION OF LOW FREQUENCY PIEZO-ELECTRIC VIBRATIONS IN QUARTZ PLATES.—J. Harrison. (*Physical Review*, 29, 4, April, 1927, p. 617.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

Further study of the phenomena described at the December meeting (*Phys. Rev.* 29, p. 366; these Abstracts, *E.W. & W.E.*, May, 1927, p. 311) indicates that the observed frequencies of vibration are sufficiently in accord with those calculated from the formula for flexural vibrations to make it fairly certain that the vibrations are of this type. In general, agreement between theory and observation is best for relatively long plates as would be expected. With longer rods the second mode of vibration having three nodes has also been observed. These facts are illustrated by numerical data and curves. An empirical formula has been derived which fits the observed data better than the theoretical equation for flexural vibrations. A plate $30 \times 10 \times 1$ mm. vibrating at 60 kilo-cycles was placed in the circuit of a type UX—210 tube as a power oscillator. The observed output power was about ½ watt, which, considering the low frequency, compares favourably with the output from a high frequency quartz oscillator.

A SHEAR MODE OF CRYSTAL VIBRATION.—W. G. Cady. (*Physical Review*, 29, 4, April, 1927, p. 617.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

In the various applications of piezo-electric quartz plates, it has until recently been customary to cut the plates with their faces perpendicular to an electric axis, when the vibrations are longitudinal. Various observers have recently found that plates cut parallel to the electric and optic axes are good oscillators, but hitherto no explanation has been offered. According to Voigt's theory of piezo-electricity, an electric field perpendicular to the electric and optic axes causes a shearing stress about the optic axis: hence the deformation of a plate cut as indicated, when in a field normal to its surface, is a shearing strain, and under an alternating impressed field vibrations are to be expected, whose resonant frequency is determined by the shear-inertia of the plate and by the elastic force of restitution. Computed and observed values of the natural frequency are in satisfactory agreement.

OPTIQUE ET RADIOÉLECTRICITÉ (Optics and wireless).—L. Bouthillon. (*L'Onde Electrique*, 6, 63, March, 1927, pp. 97-109.)

In two preceding papers (*L'Onde Electrique*, July, 1925, and November, 1926; these Abstracts, *E.W. & W.E.*, February, 1927, p. 120), the author showed that the classic problems of optics have their corresponding problems in radio and investigated the wireless equivalents of some simple optical systems.

In this third part of the article, the author sets out mathematically the general rules relating to complex systems; rules of addition, substitution and repetition, either at emission or reception, and shows how these rules become modified for real antennæ in place of the hypothetical elements at first considered.

A DIRECT COMPARISON OF THE LOUDNESS OF PURE TONES.—B. Kingsbury. (*Physical Review*, 29, 4, April, 1927, pp. 588-600.)

An account of tests leading to the following conclusion: When the amplitudes of single frequency tones are increased by equal ratios, high frequency tones increase in loudness more slowly than do low frequency tones; however, for frequencies above 700 cycles, the idea that tones are equally loud when they are an equal number of T.U. above the threshold is a very good approximation.

A STUDY OF THE REGULAR COMBINATION OF ACOUSTIC ELEMENTS, WITH APPLICATIONS TO RECURRENT ACOUSTIC FILTERS, TAPERED ACOUSTIC FILTERS, AND HORNS.—W. Mason. (*Bell System Technical Journal*, April, 1927, pp. 258-294.)

A GENERALISATION OF ELECTRODYNAMICS, CONSISTENT WITH RESTRICTED RELATIVITY AND AFFORDING A POSSIBLE EXPLANATION OF THE EARTH'S MAGNETIC AND GRAVITATIONAL FIELDS, AND THE MAINTENANCE OF THE EARTH'S CHARGE. — W. Swann. (*Philosophical Magazine*, 3, 18, pp. 1088-1136.)

ON THE QUESTION OF THE EXISTENCE OF INDUCTION EFFECTS FROM SUDDENLY STOPPED ELECTRONS, PREDICTED BY THE CLASSICAL THEORY.—S. Milner and J. Hawnt. (*Philosophical Magazine*, 3, 18, pp. 1185-1195.)

If the radiation from the moving electrons in a vacuum tube when they are suddenly stopped by the anode consists of the spherical pulses of the classical theory, an E.M.F. should be generated in a metal cylinder surrounding the anode; considerations of the energy of the pulses set a limit to the magnitude of the E.M.F. which is, nevertheless, of such a value that it should be capable of being detected by a suitably arranged galvanometer.

The experiments described show no trace of the existence of such an E.M.F. and add further evidence to the view that pulses of the kind formulated by the classical theory, if they exist, are not absorbed in accordance with classical considerations.

IONISATION BY COLLISION.—H. Huxley. (*Philosophical Magazine*, 3, 18, pp. 1056-1061.)

A note commenting on the theory advanced by Taylor in " On the Sparking Potentials of Discharge Tubes containing carefully Purified Electrodes" (*Proc. Roy. Soc.*, February, 1927).

THE USE OF GASFILLED PHOTO-ELECTRIC CELLS. —N. Campbell. (*Philosophical Magazine*, 3, 18, pp. 1041-1051.)

MAGNETIC PERMEABILITY OF IRON AND MAGNETITE IN HIGH FREQUENCY ALTERNATING FIELDS. —G. Wait. (*Physical Review*, 29, 4, April, 1927, pp. 566-578.)

Wwedensky and Theodortschik have found the magnetic permeability of iron, steel, and nickel in alternating fields to be abnormally large in certain frequency bands and nearly normal in other regions. The general appearance of the phenomenon suggested the existence, in the material, of resonators corresponding to these frequencies. The phenomenon has been observed also by Kralovec. These results are in disagreement with those of the author, who found no anomalous change in permeability at any frequency, and whose methods of investigation are described in this paper.

CONTEMPORARY ADVANCES IN PHYSICS—XIII. FERROMAGNETISM. K. Darrow. (*Bell System Technical Journal*, April, 1927, pp. 295-366.)

THERMAL AGITATION IN CONDUCTORS. H. Nyquist. (*Physical Review*, 29, 4, April, 1927, p. 614.)

Abstract of a paper presented at the New York meeting of the American Physical Society, February, 1927.

At the December meeting of the American Physical Society, J. Johnson reported the discovery and measurement of an E.M.F. due to the thermal agitation in conductors (*Nature*, 8th January, 1927, p. 50; these Abstracts, *E.W. & W.E.*, March, 1927, p. 183) The present paper outlines a theoretical derivation of this effect. A non-dissipative transmission line is brought into thermodynamic equilibrium with conductors of a definite temperature. The line is then isolated and its energy investigated statistically. The resultant formula is $E_\nu 2d\nu = 4kTRd\nu$ for the r.m.s. E.M.F. E_ν contributed in a frequency range one cycle wide by a network whose resistance component at the frequency ν is R, T and k are the absolute temperature and the Boltzmann constant. It will be observed that neither the charge nor mass nor any other property of the carrier of electricity enters the formula explicitly, but indirectly through R.

A NEW ELECTRONIC RECTIFIER.—L. Grondahl and P. Geiger. (*Journal A.I.E.E.*, March, 1927, pp. 215-222.)

A new rectifier utilising a partially oxidised disc of copper as a rectifier unit is described. The rectification appears to take place at the junction between the copper and the oxide without observable physical or chemical changes, and is similar in character to the hot-cathode type of rectification A method of designing assembled rectifiers for special purposes is outlined and some of the problems are discussed.

The discussion on the paper is given in this Journal for May, pp. 505-507.

STATIONS: OPERATION AND DESIGN.

WIRELESS BEAM COMMUNICATION. — (*Electrical Review*, 22nd April, 1927, pp. 627-629.)

Details are given of the short-wave stations built for the Imperial Telegraph Service between England and Australia.

INDIA — BEAM RADIO TELEGRAPHY. — (*Electrical Review*, 22nd April, 1927, p. 643.)

Some particulars of the stations in India linking with the Grimsby transmitter and Skegness receiver in England. The transmitting station is situated about six miles from Poona at an elevation of 2,200 ft. above sea level. Heavy fuel oil is used for power production. The receiving station lies in open country about four miles from the small town of Dhond and fifty from the Poona station.

PORTUGAL.—(*Electrical Review*, 6th May, 1927, p. 723.)

On 30th April services on the beam system were inaugurated between Lisbon and the Portuguese colonies of Cape Verde, Angola, and Mozambique. The opening of these services completes the network of wireless communication which the Marconi Company undertook to construct in accordance with the concession obtained from the Portuguese

Government in 1922. Direct wireless communication is now established between Lisbon and all the principal Portuguese colonies, services to Madeira and the Azores having been opened in December last. Direct services betweeen Lisbon and London, Paris, and Berlin have also been opened during the last few months, and a direct service with Rio de Janeiro is expected to be inaugurated almost immediately.

UNE VISITE À RADIO-BARCELONE (Visit to the broadcasting station at Barcelona).—E. Caranove. (*Radio-Revue*, May, 1927, pp. 363-367.)

Account of a visit to this station which in February of last year was removed from the town to the top of Mount Tibidabo (582 metres), ascended by funicular railway. The T-shaped antenna is supported by two lattice masts 50 metres high, so that it is now more than 600 metres above sea level and higher than most aerials in Europe. The station is found six times more effective since its transfer. The energy is obtained from the town mains supplying the low and high tension dynamos, through synchronous motors respectively of 4 and 8 h.p. One low tension dynamo provides current at 22 volts for the filaments and the other at 250 volts for the grids. The two high tension dynamos, which are identical and can be coupled in series, supply current of 1 amp 35 at 2,000 volts. The transmitting apparatus comprises four cylindrical Western Electric valves, type 6A, and the wave-length is 325 metres or 344 with a power of 1kW antenna. The studio remains in the town at the Hotel Tivoli.

LE POSTE DE NANTES DE LA MARINE FRANÇAISE (The French naval station at Nantes).—(*Radio-Revue*, May, 1927, pp. 360-362.)

Views are shown of the equipment.

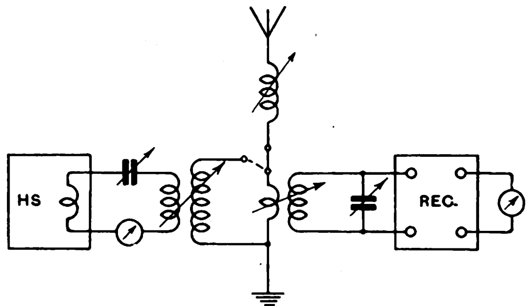
MEASUREMENTS AND STANDARDS.

QUANTITATIVE MEASUREMENTS ON RECEPTION IN RADIO TELEGRAPHY.—G. Anders. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 297-311.)

Abstract of an article that appeared in *Elektrische Nachrichten-Technik*, 12, 2, 1925.

After discussing previous systems of measuring field intensities, their limitations and sources of error, referring particularly to the work of Hollingworth, Vallauri, Guierre and Round in Europe and of Pickard, Austin, England and Früs in America, the author describes the method he has perfected in the German Bureau of Telegraph Engineering. The scheme employs the usual elements in signal strength measuring work, viz., wave collector, receiver set with indicator and calibrating apparatus. The basic arrangement is shown below :

The calibrating method is essentially a current-measuring device. Referring to the figure, the secondary receiving circuit is coupled through the mutual inductance to a small coil, which is alternately switched to the ground lead of the antenna circuit and to the ends of a coil of a relatively large number of turns and small effective resistance. This latter circuit is in turn coupled with the calibrating oscillator HS by means of a mutual inductance. These two coils may be regarded as a current transformer. The primary current is measured by means of a vacuum barretter (hot-wire resistance) and the secondary current is made equal to the current produced



by the receiving signal, as indicated by the meter in the output of the receiver. Then knowing the ratio of transformation of the current transformer it is possible to determine antenna currents which do not allow of direct measurement.

The details of the construction of the set are discussed at length.

THE FREQUENCY CHECKING STATION AT MARE ISLAND.—G. Royden. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 313-318.)

This paper describes the frequency checking station at Mare Island Navy Yard for the purpose of measuring the transmitted frequencies of naval radio stations extending from St. Paul, Alaska, to San Diego, California, as far west as Cavite, Philippine Islands, and as far south as Tutuila, Samoa. The intention, of course, is to secure that each station maintains its assigned frequency and thus prevent interference.

The standard frequency meter consists of two variable air condensers and a set of ten inductance coils, wound with finely divided and insulated radio-frequency cable on bakelite tubes. The calibration of the meter depends primarily on the accuracy of a steel tuning fork, carefully adjusted to 1,000 cycles in comparison with the standard clock at Paris, and kept at a constant temperature. The tuning fork and frequency meter are compared in a screened room by means of a multivibrator together with an amplifier and a heterodyne oscillator. The method is discussed in detail.

THE EXACT AND PRECISE MEASUREMENT OF WAVELENGTH IN RADIO TRANSMITTING STATIONS — (R. Braillard and El Divoire). (*E.W. & W.E.*, June, 1927, pp. 322-330.)

Parts A and B: General consideration of the broadcast problem and description of wavemeter.

SYMPOSIUM ON HIGH FREQUENCY MEASUREMENTS. —A. Knowlton. (*Journal A.I.E.E.*, May, 1927, pp. 487-491.)

Résumé of a series of 15 papers dealing with measurements at high frequencies, the preparation of which constituted the major activity of the

Committee on Instruments and Measurements during the year 1926-27. Copies of the papers can be obtained from the Institute Headquarters.

ANALYSER FOR COMPLEX ELECTRIC WAVES.—A. Landeen. (*Bell System Technical Journal*, April, 1927, pp. 230-247.)

For several years there has been in use in the Bell Telephone Laboratories special apparatus by means of which a single component of a complex periodic current wave may be selected from the remaining components and its amplitude determined. The sensitivity and selectivity of this apparatus are such that components of small amplitude may be accurately measured even in the presence of other components of several hundred times the amplitude and differing but little in frequency. With the latest improved form it is now possible to measure current components having amplitudes as low as 10^{-7} amperes with a possible error of 10 per cent. For such minute currents this is within the error that might be introduced by the external apparatus such as attenuators and thermocouples together with their calibration charts.

Though the apparatus described, which can work over the range from about 3,000 to 100,000 cycles was primarily designed for use in current wave analysis work, it may be readily adapted to voltage analysis. Suitably calibrated it can also be used as a frequency meter of extremely high precision.

The third chapter is concerned with the selection of the wavelength on which it is necessary to work for measurements made at high frequency to give the same figure as those carried out electrostatically. A wavelength of 1,000 metres was found suitable for the circuits employed. The last chapter gives the circuit-arrangement and results.

DISCUSSION ON IMPORTANCE OF LABORATORY MEASUREMENTS IN THE DESIGN OF RADIO RECEIVERS.—W. Macdonald. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 329-340.)

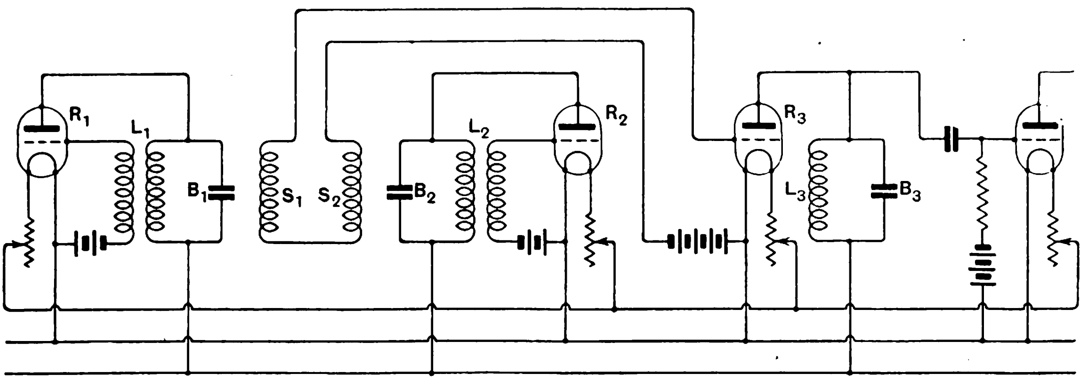
Discussion of the paper that appeared in *Proc. Inst. Radio Engineers*, of last February, pp. 99-111 (these Abstracts, *E.W. & W.E.*, May, 1927, p. 310).

DISCUSSION ON SIMPLIFIED S.L.F. AND S.L.W. DESIGN.—O. Roos. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 319-326.)

Discussion on the paper that appeared in *Proc. Inst. Radio Engineers*, of December, 1926, pp. 773-780.

SUBSIDIARY APPARATUS AND MATERIALS.

TON FREQUENZ-WECHSELSTROMGENERATOR (Audio frequency alternating current generator.—G. Lubszynski. (*Telefunken Zeitung*, 8, 44, pp. 57-60.)



ÜBER MESSUNGEN AU PIEZO-ELEKTRISCHEN KRISTALLEN (Measurements with piezo-electric crystals).—K. Heegner (*Telefunken Zeitung*, 8, 44, pp. 60-63.)

Discussion of the measurement of the damping of an oscillating crystal.

CONTRIBUTION À LA REALISATION D'UN ETALON DE FAIBLE CAPACITÉ (Contribution to the production of a standard of small capacity.)—F. Bedeau (*L'Onde Electrique*, 6, January, 1927, pp. 19-46.)

Second part of an article begun in the December number of *L'Onde Electrique* (these Abstracts, *E.W. & W.E.*, March, 1927, p. 181), containing the third and last chapters on the cylindrical air condenser.

By superimposing two high frequencies and then rectifying, a note frequency is obtained equalling the difference of the high frequencies. In order to prevent these frequencies as well as the low frequency passing beyond the rectifier, a low frequency oscillatory circuit is inserted in the rectifier anode lead. The circuit arrangement is shown above:

LES HAUT-PARLEURS À GRANDE PUISSANCE DE L'EXPOSITION DE BERLIN (Powerful loud-speakers at the Berlin Exhibition.—(*Radio Revue*, May, 1927, p. 370.)

The most powerful of the German loud-speakers are the "Falz" and the "Blatthaller" types. The "Falz" is an electro-dynamic instrument in which the amplified microphonic currents traverse a thin strip of aluminium about 50 cm. long under the

influence of a very powerful magnetic field. The strip thus becomes the seat of energetic vibrations, reproducing those of the speech or music, and communicating them directly to the surrounding air. The Blatthaller works on a similar principle: strips of copper which are traversed by the amplified currents and immersed in the field of a very powerful electro-magnet, are fixed to a membrane of "Pertinax," transmitting the vibrations to the surrounding air.

These loud-speakers are controlled by microphones which are in reality microphonic condensers. The condensers consist of a fixed plate pierced with holes, at a very small distance behind which there is an extremely thin sheet of aluminium. Vibrations of the voice cause the distance between the plates to vary and thus the capacity of the condenser. The condenser forms part of a high frequency circuit connected to the grid of a valve: the variations of capacity bring about variation of the high frequency current which is then detected by a second valve and subsequently amplified by a low frequency amplifier with seven valves, of which the last is a power valve.

COIL-DRIVEN LOUD-SPEAKER WITH PERMANENT MAGNETS. — H. Lloyd (*Wireless World*, 1st June, 1927, pp. 689-692.)

UN NOUVEL ISOLANT: "LA THIOLITE" (A new insulator: thiolite). — *Radio-Revue*, May, 1927, p. 376.)

Description of the properties of this new insulator, giving the following numerical data: resistivity 300×10^8 megohms/cm.; specific inductive power 4.5; dielectric loss at high frequency $C = 54 \times 10^{-6}$; dielectric rigidity—the true breakdown voltage for disc electrodes 1 mm. apart is given as 34 kilovolts.

THE LOGARITHMIC CONDENSER.—F. Haynes. (*Wireless World*, 18th May, 1927, pp. 621-626.)

L.T. AND H.T. SUPPLY FROM D.C. MAIN.—A. Robertson. (*E.W. & W.E.*, June, 1927, pp. 336-338.)

MISCELLANEOUS.

U.S.A. FEWER STATIONS ADVOCATED.—*Electrical Review*, 29th April, 1927, p. 683.)

According to *World Radio* a plan for the reduction of the number of broadcasting stations in the United States from 733 to 364 has been submitted by the American Engineering Council to the Federal Radio Commission. Under the scheme there would be 64 national stations and 300 local stations, the former operating in the band between 550 and 1,250 kilocycles, *i.e.*, from 240 to 545 metres, while the local stations would be confined to the range of from 1,250 to 1,500 kilocycles, or from 240 down to 200 metres.

BOLIVIAN TELEGRAPHS.—(*Electrician*, 6th May, 1927, p. 503.)

A contract has been made between Marconi's Wireless Telegraph Co., Ltd., and the Government of Bolivia, by which the company will undertake the control and operation of the postal, telegraph, and wireless services of Bolivia for twenty years. This is the second contract of this kind which the Marconi Company hold in South America, the first being with the Peruvian Government in 1921, since when the annual deficits have been converted into a substantial profit to the National Exchequer, amounting for the years 1924-1925 to 239,968 Peruvian pounds. Particular attention is to be paid to the development of wireless communication.

WIRELESS TELEGRAPH COMMUNICATION.—Lieut. Col. Chetwode Crawley. (*Electrical Review*, 15th and 29th April, and 13th May, 1927.)

A review of the present position of maritime safety services, commercial communication, and point-to-point telegraphy in view of the proposed modified requirements and regulations to be discussed at the International Conference to be held in the United States next autumn.

TRANSATLANTIC RADIO TELEPHONY.—R. Bown. (*Bell System Technical Journal*, April, 1927, pp. 248-257.)

An attempt to provide a *connected* story of how the final result was built up through several years of continued effort.

A NEW TALKING FILM SYSTEM.—A. Dinsdale. (*Wireless World*, 25th May, 1927, pp. 645-647.)

Description of a new system, with cinematograph and sound records on the same film, which has just been developed by a group of engineers belonging to the General Electric Company.

A SUCCESSFUL PUBLIC DEMONSTRATION OF TELEVISION BETWEEN WASHINGTON AND NEW YORK.—A. Dinsdale. (*Wireless World*, 1st June, 1927, pp. 680-686.)

AN ANALYSER FOR THE VOICE FREQUENCY RANGE. —C. Moore and A. Curtis. (*Bell System Technical Journal*, April, 1927, pp. 217-229.)

NOTE SUR UN SYSTÈME DE COMMUNICATIONS ELECTRIQUES SECRÈTES (Note on a system of secret electric communication).—J. Jammet. (*L'Onde Electrique*, 6, 63, March,, 1927, pp. 135-136.)

Reply to the criticism by M. Vincent, published in *L'Onde Electrique*, of November, 1926, of the secret system put forward by M. Jammet in *L'Onde Electrique*, of August, 1926.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

RADIO-ESPLORADO DUM LA EKLIPSO.

Noto pri la observadoj farotaj dum la suna eklipso je 29a Junio.

PROPRECOJ DE CIRKVITOJ.

KLINA INDUKTECO.—C. R. Cosens.

Noto pri la efektiva indukteco de ferkernaj ŝokbobenoj aŭ transformatoj. La aŭtoro difinas *Klinan Induktecon* kiel la kvanton $\frac{\text{Ŝanĝo de Flur Turnoj}}{\text{Ŝanĝo de Kurento}}$ kiam la kurenta ŝanĝo estas malgranda kaj estas surmetita sur relative grandan kontinuan kurenton.

Post diskutado pri la A.K. indukteco de ŝokbobeno, oni montras, ke provoj de ĉi-tio ne montras eĉ proksimume la efektivan induktecon de la ŝokbobeno, kiam uzita je la anoda cirkvito de valvo. Poste estas priskribita metodo mezuri klinan induktecon. Per tiu metodo oni sendas kaj K.K. kaj A.K. tra la ŝokbobenon mezurotan, kaj tra rezistancon seriearanĝitan je ĝi. Kondensatoroj apartigas la A.K. fonton for de la bateria fonto, dum ŝokbobenoj en la lasta tenas malalte la alternan kurenton tra la baterio kaj miliampermetro. La A.K. voltkvantoj trans la ŝokbobeno kaj trans la rezistanco estas mezuritaj per valva voltmetro.

Diskutitaj estas metodoj fari la provon, rezultoj, k.t.p., dum aldonaĵo diskutas la eraron kaŭzitan pro malzorgo pri la efektiva bobena rezisteco.

MEM-INDUKTECO DE REKTAJ FADENOJ.—R. M. Wilmotte.

Oni montras, ke la desegno de ŝokbobeno por tre altaj frekvencoj (ekz., 10^7 aŭ 10^8 cikloj) fariĝas pli kaj pli grava. Por malgrandigi la efekton de memkapacito, la fadenoj devas esti spacigitaj, tiel ke la distanco inter fadenoj estas 200-oble pligranda ol la fadena diametro. En ĉi tiu okazo ne gravas, ĉu la fadeno estas streĉita laŭ rekta linio aŭ volvita laŭkutime. La mem-indukteco de cirkvito kaj la komuna indukteco inter ĝiaj partoj estas poste konsideritaj, diversaj esprimoj estante donitaj por L kaj M kaj por kapacito. Tabelo kaj (kurvo montras la induktecon kaj kapaciton dum la proporcia distanco/radiuso estas pligrandigita. Per tio, oni konkludas, ke la distanco de la diversaj partoj de la cirkvito devas esti proksimume 200-oble pli granda ol la diametro, kaj por fari ĉi tion en modera spaco oni devas uzi maldikan fadenon, kiel ekzemple, 47 S.W.G. Je ondolongoj de nur kelkaj metroj oni trovos, ke estas tre oportune uzi nur rektan pecon de fadeno de 47 S.W.G., kiu havas la aldonan avantaĝon, ke ĝi bone apartigas la bornojn.

MEZUROJ KAJ NORMOJ.

LA ĜUSTA KAJ PRECIZA MEZURADO DE ONDOLONGO ĈE RADIO-SENDADAJ STACIOJ.—Raymond Braillard and Edmond Divoire.

La aŭtoroj estas respektive Prezidanto kaj Sekretario de la Teknika Komisiono de la *Union Internationale de Radiophonie.*

La artikolo unue diskutas la malfacilecon de komuna interfero de du brodkastaj stacioj kaj la ĝeneralan aferon de altfrekvenca precizeco kaj konstanteco. La ordinara ondometro, oni diras, suferas pro la difektoj de du vastaj ondgrupoj, malkonstanteco de normigado, tro alta amortizo, kaj manko de ŝirmado kontraŭ elektrostatikaj efektoj. La Teknika Komisiono de la U.I.R. do decidis (*a*) studadi novan ondometron, precizan, stabilan, kiu ampleksos tre mallarĝan grupon ĉirkaŭ la funkcia frekvenco, kaj ekipi ĉiun stacion per unu ondometro, (*b*) produkti ĉi tiujn amase, (*c*) normigi ĉiujn ondometrojn en unu laborejo ekipita per unusola frekvenca normo.

La cetero de la nuna parto poste traktas pri priskribo de la ondometro.

La multobla paralela-plata tipo de kondensatoro estis rejetita, kaj oni decidis adopti kondensatorojn faritajn plejparte el du koncentraj cilindroj. Oni donas matematikan konsideradon pri la evoluigo. La fiksaj kaj varieblaj kondensatoroj estas formitaj en la unu sama organo, la platoj estante koncentraj cilindroj kun la ekstera cilindro kovrita. Oni obtenas kapacitan variadon per movo de du kvadrantoj de cilindroj (apartaj 180°, kaj konektitaj elektre al la ekstera cilindro), kiuj movas rilate al du aliaj kvadrantoj, kiuj estas plilongigaĵoj de la interna cilindro. La induktanco estas bobeno de nuda kupra fadeno, subtenita de ses izolantaj strioj, kiuj formas la facetojn de sesangula prismo. La indikatora cirkvito estas unuobla turno de latuna strio funkciiganta resonancan indikatoron je la formo de inkandeska lampo aŭ termokuplo.

La nuna parto finiĝas per diskutado pri la plej bona proporcio de indukteco je kapacito.

RICEVADO.

DESEGNO KAJ KONSTRUO DE SUPERHETERODINA RICEVILO.—P. K. Turner.

Daŭrigita el antaŭa numero.

En la nuna parto la aŭtoro daŭrigas konsideradon pri la ekvilibro de la enmeta (detektora oscilatora) cirkvito, kaj pri la ĝenerala aranĝa metodo de ĉi tiu cirkvito. La ĝenerala aranĝo de la kompleta aparato estas poste montrita, inklusive la aranĝon

refleksi du el la interaj frekvencaj valvoj, por ke ili ankaŭ funkciu je aŭd-frekvenco. La intera frekvenco uzita estas ĉirkaŭ 100 kilocikloj (3,000 metroj), kun varieblaj kondensatoroj ĉe ĉiuj I.F. transformatoroj, tiel ke, por longaj ondoj, la unua valvo ĉesas oscili, kaj la I.F. amplifikatoro estas uzita senpere kaj agordita al la signalo.

La aŭtoro poste konsideras la diversajn cirkvitojn detale, kun tre kompletaj notoj pri iliaj elektraj dimensioj. Li montras aranĝojn por uzi unuoblan k.k. instrumenton kiel filamentan voltmetron kaj anodan miliampermetron por ĉiu valvo. La detala desegno de la enmeta cirkvito estas diskutita kaj ilustrita, sekvita de simila traktado pri la interfrekvenca amplifikatoro kaj refleksaj cirkvitoj.

La artikolo estas daŭrigota.

Malalt-Tensia kaj Alt-Tensia Provizado per K. K. Ĉeftuboj.—A. Robertson.

La aŭtoro montras tri-valvan ricevilon konektitan al aranĝo por obteni altan tension kaj krad-potencialon pere de 250-volta kontinukurenta provizado, kie la pozitiva flanko de la sistemo estas terigita.

Oni ilustras diversajn alternativajn aranĝojn konektajn, kun rimarkigoj de la aŭtoro pri iliaj respektivaj efikecoj glatigi zumadon.

VALVOJ KAJ TERMIONIKO.

Senfadenaj Sendaj Valvoj.

Resumoj de tri prelegoj legitaj antaŭ la Senfadena Sekcio de la Institucio de Elektraj Inĝenieroj, Londono, je la 4a Majo, kaj de la ĝenerala diskutado, kiu sekvis la legadon de la prelegoj.

La prelegoj estis :—

1. La Demuntebla Valvo "Holweck," de C. F. Elwell, M.I.E.E.

2. Silikaj Valvoj je Senfadena Telegrafio, de H. Morris Airey, C.B.E., M.I.E., G. Shearing, B.Sc., M.I.E.E., kaj H. G. Hughes, M.Sc.

3. Valvoj kun Malvarmigitaj Anodoj, kaj Vivoj de Sendaj Valvoj, de W. J. Picken, A.M.I.E.E.

La unua prelego mallonge priskribas la Holweck Molekula Pumpilo, kaj demuntebla speco de valvo uzita kun ĝi, la vakuo estante konservita per funkciigo de la pumpilo.

La dua prelego priskribas silikajn valvojn, kiel estas uzitaj je Brita Marista Senfadena Telegrafio, ilustrante metodojn por fiksi en elektrodaj konduktoroj, ĝeneralan konstruadon kaj taksadon, kaj lastatempe evoluigitan metodon de anoda malvarmigado per cirkulado.

La tria prelego unue priskribas valvojn kun malvarmigitaj anodoj, fabrikitajn de la Marconi-Osram Valva Kompanio, kun detaloj pri ilia konstruado kaj taksado. La lasta parto de la prelego traktas pri la vivo de sendaj valvoj, la detaloj donitaj estante plejparte por valvoj de la radiada speco.

Presitaj ankaŭ estas la ĝenerala diskutado kaj la respondoj de la aŭtoroj.

DIVERSAĴOJ.

Resumoj kaj Aludoj.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

Matematiko por Senfadenaj Amatoroj.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto traktas pri la cirkla mezurado de anguloj ; areo (de triangulo, paralelogramo, cirklo, k.t.p.) ; vektoroj ; la adicio de vektoroj ; la multobligo de vektoro per numero ; operatoro kaj operando ; unuo-vektoroj ; la skala produkto de vektoroj, k.t.p.

Libra Recenzo.

Oni donas recenzon pri la verko *Wireless Loud Speakers* (Senfadenaj Laŭt-paroliloj), Praktika Manlibro priskribanta la Principojn de Funkciigo, Funkciado, kaj Desegnado. De N. W. McLachlan, D.Sc., M.I.E.E. Eldonita de Iliffe & Sons, Ltd., Londono, eldonistoj de *Experimental Wireless*.

"A Fine British Magazine."

" It is disappointing to note that one of the best British technical journals, Experimental Wireless and The Wireless Engineer, published in London by Iliffe & Sons, has been compelled to raise its subscription price to two shillings and sixpence per copy on account of 'lack of support by English advertisers.' Without a doubt if Iliffe & Sons are compelled to pass the hat to keep this magazine going, they will receive strong support from American engineers, for this paper is without a peer as an organ for serious engineers and experimenters. In England a research is undertaken, it seems, with the love of pure science in the investigator's heart and not with one hand tied by production department threats. The English may pursue roundabout methods, but the end point is final and the answer is complete. No American deeply interested in radio science can afford to be without Experimental Wireless, even were the price raised to five or six 'bob' per month."—*Radio Broadcast, U.S.A.*

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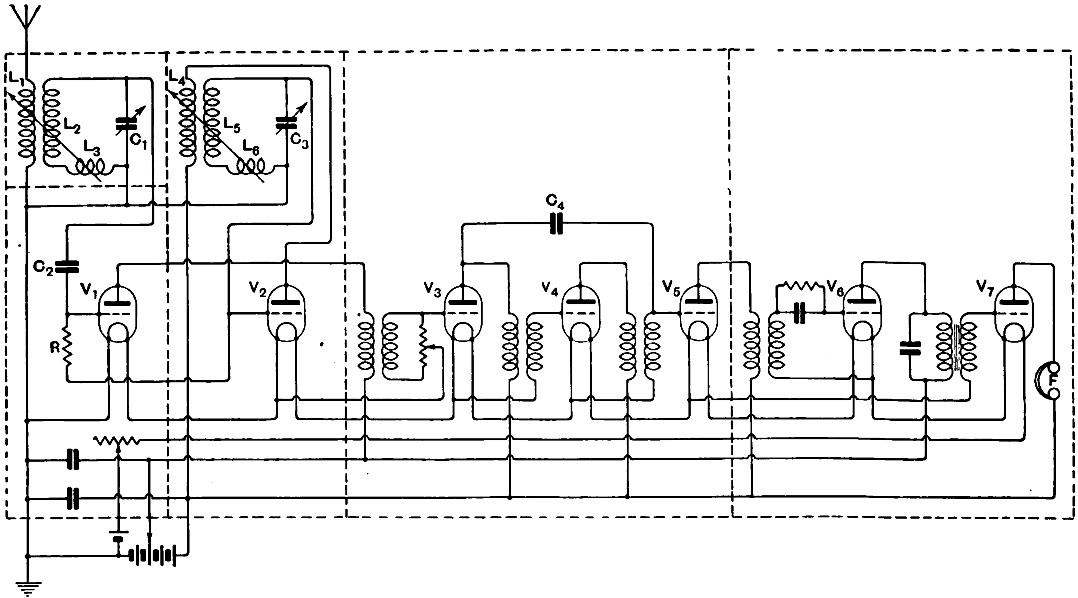
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

A SUPERHETERODYNE RECEIVER.

(*Application date*, 18*th December*, 1925.
No. 267,617.)

A superheterodyne receiver utilising a particular form of circuit arrangement and incorporating some rather novel connections is described by Standard Telephones and Cables, Limited, in the above British Patent. The object of the invention is to provide a receiver in which the alteration of the tuning, either of the input circuit or the local oscillator shall have no mutual effect. This is accomplished by using the arrangement shown in the accompanying diagram, the dotted portions representing what may be screened sections. The aerial circuit comprises a variable inductance L_1 coupled to a fixed inductance L_2 and a variable inductance L_3 tuned by a condenser C_1. This is connected to the grid of the first detector valve V_1 through a condenser C_2 in the normal manner. The oscillator valve V_2 is connected in the usual manner, and comprises an inductance L_4 coupled to a grid circuit consisting of a fixed inductance L_5 and a variable inductance L_6 tuned by a condenser C_3. The grid of the oscillator valve V_2 is connected to the grid of the detector valve through a resistance R of about 2 megohms. This resistance R acts partly as a grid-leak to the detector valve, and partly as a means of transferring the oscillations to the detector valve from the oscillator. The remaining portion of the circuit will not be described in detail, as it is more or less normal. The output of the detector valve is coupled through a transformer T_1 to the grid circuit of the first amplifier, the magnitude of the applied potentials being controlled by a potentiometer P in the usual way. The valves V_3, V_4 and V_5 act as intermediate amplifiers, while the valve V_6 is arranged as a second detector. The specification states that the



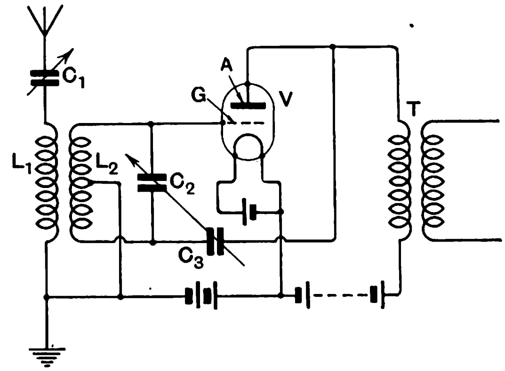
receiver thus arranged gave bad quality, probably due to the fact that certain portions of the intermediate amplifier were resonant. This was overcome by the introduction of a small condenser C_4 between the anode of the valve V_3 and the grid of the valve V_5, thus producing a non-regenerative effect. This condenser, of course, must not be too large, or it will lower the amplification considerably. The output of the second detector is passed through a low frequency transformer to the final valve V_7, the anode circuit of which contains the telephones F.

VARIABLE NEUTRALISATION.

(*Application date*, 3*rd June*, 1926.
No. 269,355.)

A circuit for the purpose of varying the amount of neutralisation, and one incorporating a special form of condenser construction is described by Standard Telephones and Cables, Limited, in the above British Patent. It is pointed out that the

ordinary neutralising condenser may be adjusted so that exact capacity neutralisation is obtained, or, alternatively, over or under neutralisation. It is further stated that it frequently happens that maximum selectivity and signal strength is obtained

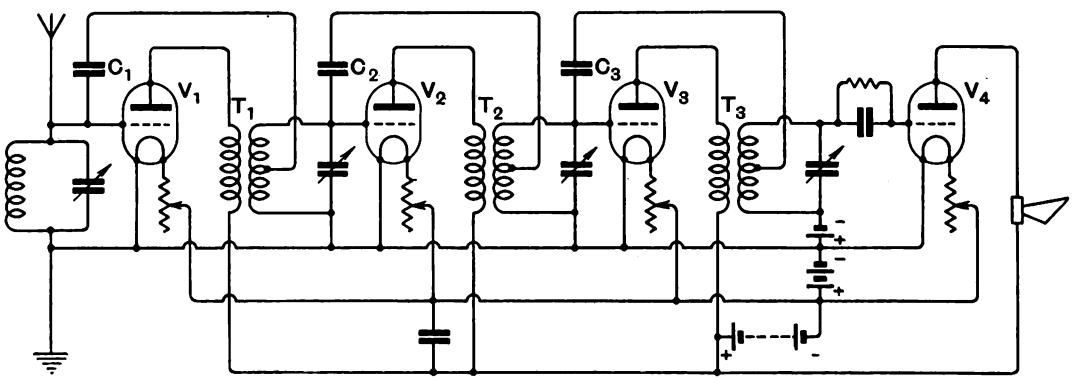


when a slight degree of regeneration is present, that is, the circuit may be over neutralised, or under neutralised, as the case may be. If the circuit is exactly neutralised the value of the neutralising condenser remains substantially constant throughout the whole frequency range of the tuned circuit, whereas, when a certain amount of regeneration is desired, the value of the balancing condenser has to be varied in accordance with the variation of the tuning condenser. According to the invention, however, the two condensers are mechanically combined, and one circuit arrangement adopting this principle is shown in the accompanying diagram. Here the aerial is tuned by a condenser C_1 and an inductance L_1. This is coupled to an inductance L_2 tuned by a condenser C_2. The mid point of the inductance L_2 is connected to the filament and earth, while one end is taken to the grid G of the valve V, and the other end is taken through a variable balancing condenser C_3 to the anode A. The anode circuit is shown to contain the primary of a transformer T. The tuning condenser C_2 and balancing condenser C_3 are nechanically linked so that any variation of the tuning condenser effects a desired change in the balancing condenser. A further feature of the invention is the construction of a variable condenser with a separate insulated plate working in conjunction with another plate on the rotor of the main tuning condenser so that the balancing condenser is constituted by these elements.

CONSTANT AMPLIFICATION.

(*Convention date* (*S.A.*), 10*th October*, 1925. *No.* 259,613.)

Another Hazeltine neutralised circuit is described in the above British Patent Specification by Hazeltine Corporation and W. A. MacDonald. In dealing with neutralised amplifiers the specification mentions that in any particular stage of amplification there is a frequency at which the amplification will be a maximum dependent upon the relation between the inductance and capacity present in the tuned circuit when associated with its particular valve and also the mutual inductance between primary and secondary. In the case of a multi-stage receiver of this type using similar transformers this frequency of optimum amplification is usually the same for each stage. Since the amplification rises in geometric progression it follows that the resultant amplification in a multi-valve amplifier at this optimum frequency will be very much greater than over the whole frequency band for which the amplifier is desired to function. Accordingly, an amplifier is constructed so that the optimum amplification occurs at a different frequency in each stage. This will, therefore, have the effect of levelling the total amplification over the entire band. The accompanying illustration shows a suitable circuit which will be described briefly. Valves V_1, V_2 and V_3 act as radio-frequency amplifiers, while the valve V_4 is used as a detector. The successive stages are coupled respectively by transformers T_1 T_2 and T_3. These are of the tapped secondary neutrodyne type, neutrodyne condensers C_1, C_2 and C_3 respectively being connected between the tapping point on the secondary and the grid of the preceding valve. The three transformers are

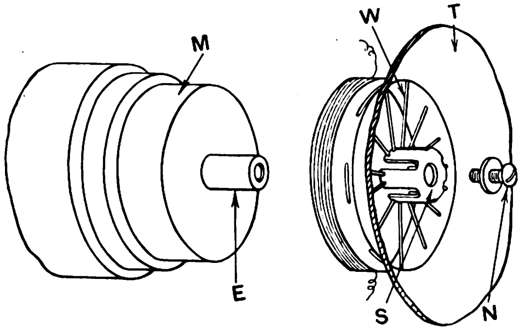


tuned by separate condensers, and the transformers are so constructed that the optimum amplification frequency is different for each stage. Since the remainder of the circuit is normal it will not be described in further detail.

RICE-KELLOGG DETAILS.

(*Convention date* (*U.S.A.*), *9th January*, 1925.
No. 245,796.)

Some further details of the Rice-Kellogg type of speaker are given in the above Specification by The British Thomson-Houston Company, Limited, C. W. Rice, and E. W. Kellogg. Readers are, no doubt, familiar with the broad principle of the Rice-Kellogg speaker, which has already been given in these columns, but the present invention

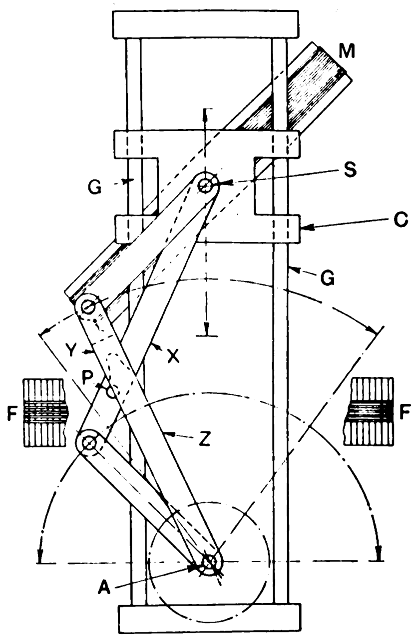


relates to certain modifications which are of considerable importance. As the general principle of the speaker is therefore well known, certain minor points only will be illustrated. The present specification relates chiefly to the method of supporting the cone. The cone *C* is of rigid material, and is fixed to an annular support by means of a ring *R* of some flexible material such as thin rubber or silk. The specification points out that it is necessary that the restoring force on the diaphragm should be such that the natural frequency is very low, and preferably of the order of about 50 cycles, although it is mentioned that satisfactory results can be obtained with a natural frequency as high as 200 cycles. Owing to the very light nature of the flexible suspension of the edge of the diaphragm care has to be taken that the truncated end supporting the coil drive shall not touch the magnetic poles, and a special form of suspension is therefore adopted. The end of the circular magnet pole *M* is provided with an extension *E* to which is fixed a spider *S* by means of a screw and washer *N*. The truncated end *T* of the cone is fixed or laced to the spider by means of wires or strings *W*. This, it is stated, enables the cone to move with a plunger action without any transverse motion occurring. The specification contains a considerable amount of important information regarding sizes and angles of cone, and details of many other interesting points, far too numerous to deal with in a limited space. Readers who are particularly interested in this type of speaker are referred to the specification for greater detail, as it appears to be of very considerable importance. For example, the necessity of not enclosing the air behind the diaphragm is dealt with. If this is done " box resonance " occurs. Another important point is the inclusion of a short circuited turn or ring round the end of the pole piece to act as a " smoothing device " against any fluctuations which may occur in the field winding should it be supplied from rectified alternating current, or be affected by commutator ripple in a D.C. supply.

VARIABLE COUPLING.

(*Application date, 22nd January*, 1926.
No. 269,668.)

A form of variable coupling particularly suitable for transmitting inductances is described by J. K. im Thurn and G. W. Harris in the above British Patent. The arrangement should be almost self explanatory. The fixed coil is shown at *F*, while the movable coil is shown at *M*. This is mounted on a shaft *S* fixed to a carriage *C* working on vertical guides *G*. The end of the shaft *S* is provided with a link motion actuated by a spindle *A*. It will be seen that rotation of the spindle *A* will cause the link motion to make the coil *M* rotate on the carriage *C*, and simultaneously cause the carriage to move upwards or downwards according to the direction of rotation of the spindle. As the farthest point of travel of the coil *M* is approached a pin *P*



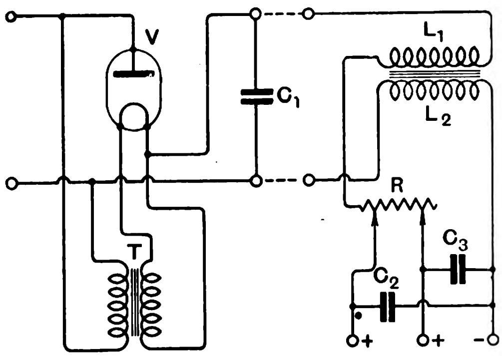
in the link arm *X* engages a guide plate *Y* on the link arm *Z*, and carries it over the top dead centre in a direction depending upon the rotation of the spindle *A*.

A SMOOTHING CIRCUIT.

(*Application date, 2nd March*, 1926.
No. 267,701.)

A smoothing circuit for use with a valve rectifier, in which the choke elements are arranged in an unusual manner is described in the above

British Patent by W. Diggle in the above specification. The filament of the rectifying valve V is heated from the secondary winding of a transformer T connected with the main A.C. supply. The supply is connected to the rectifier in the usual

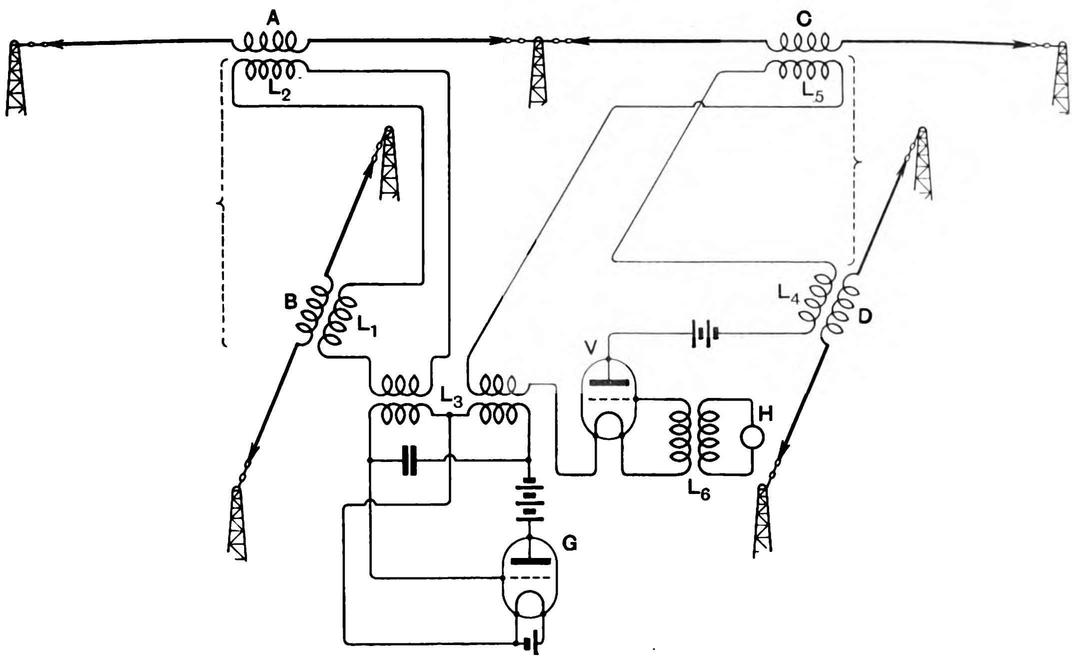


manner, and an integrating condenser C_1 is connected before the chokes. The remainder of the filter circuit is constituted by another condenser C_2 across two chokes L_1 and L_2 in each lead respectively. These two chokes are coupled together and are wound on the same core. An intermediate voltage is derived through a series resistance R and a shunt condenser C_3.

SHORT WAVE TRANSMISSION.

(*Convention date* (*Germany*), *1st October*, 1925. *No.* 259,226.)

A system of short wave transmission designed to overcome fading, skipped distance, and similar troubles is described in the above British Patent by Telefunken Gesellschaft für Drahtlose Telegraphie, M.B.H. The invention consists essentially in the superimposition of two circularly polarised waves whose mutual phase relationship is periodically changed. A very detailed explanation of what probably happens in the case of these undesired effects, and the manner in which the present invention functions is given in the specification. Essentially the arrangement shown in the invention shows four aerials, A, B, C and D. Aerials A, B and C, D are respectively arranged a quarter of a wavelength apart. These are fed by a short wave generator G connected in the normal manner. Aerials A and B are fed through a series link arrangement L_1, L_2 and L_3, while aerials C and D are fed through another link arrangement, L_4, L_5 and L_6, the inductances being respectively coupled to appropriate aerial coils and coils in the generator circuit. In series with the link feed L_4, L_5, L_6 is a valve V. The grid circuit of this is energised by a source of oscillation H which periodically interrupts the feeds to the aerials C and D. Such an arrangement results in periodic mutual phase change between the superimposed circularly polarised waves. The specification indicated how the various constants may be calculated.



EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. AUGUST, 1927. No. 47.

Editorial.

A Simple Indirect Method of Measuring Grid Current.

In the March number of the *Zeitschrift für Hochfrequenztechnik*, von Ardenne describes a novel method of measuring very small grid currents by means of a galvanometer or micro-ammeter which, used directly, would be too insensitive for the purpose. Grid currents of 10^{-10} to 10^{-9} amperes can be measured by means of an instrument capable of measuring 10^{-7} to 10^{-6} amperes. The method is based upon the fact that if a grid leak of known value is employed the grid current causes a fall of potential along the leak resistance, and thus alters the grid potential by an amount which is determined from the

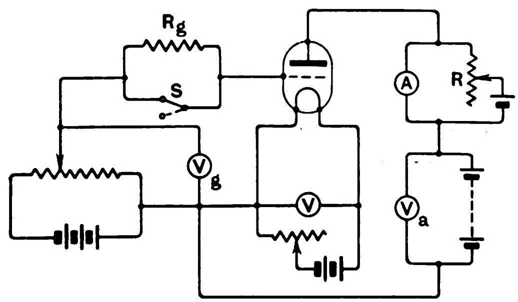


Fig. 1.

change it produces in the anode current. It is thus an application of the valve voltmeter principle to the determination of one of the characteristics of the valve itself. Fig. 1 shows the circuit arrangements; *A* is the micro-ammeter or galvanometer in the anode circuit, the reading of which is normally

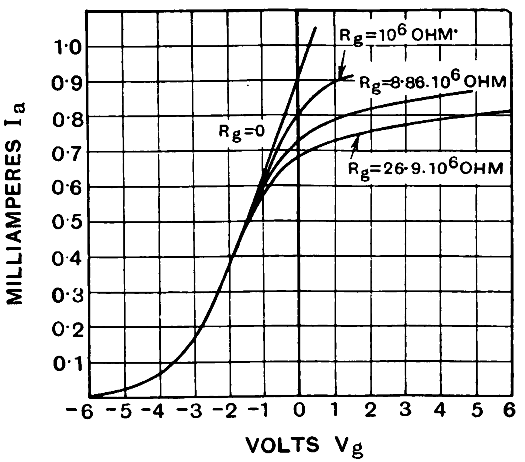


Fig. 2.

adjusted to zero by means of a cell and the resistance *R*. The grid battery is provided with a potential divider, across which the voltmeter V_g is connected. The switch *S* enables the grid resistance R_g to be inserted or short-circuited. So long as no grid current flows, it is immaterial whether R_g is in or out, but if there is any grid current a fall of potential occurs in R_g and the anode current is modified by its insertion. This is clearly shown in Fig. 2, which shows how the anode current varies with V_g for various

values of R_g. In Fig. 3 the upper curve is the ordinary characteristic with R_g cut out and the lower curve that with R_g inserted. Since the points A and B represent the same anode current they must also represent the same actual grid voltage; it will be noticed that V_g in Fig. 1 reads the voltage tapped off the grid battery, but not the actual voltage of the grid except when $R_g=0$ or $I_g=0$. The vertical intercept BC in Fig. 3 represents the decrease of anode current caused by the insertion of R_g, which decrease could have been produced without inserting

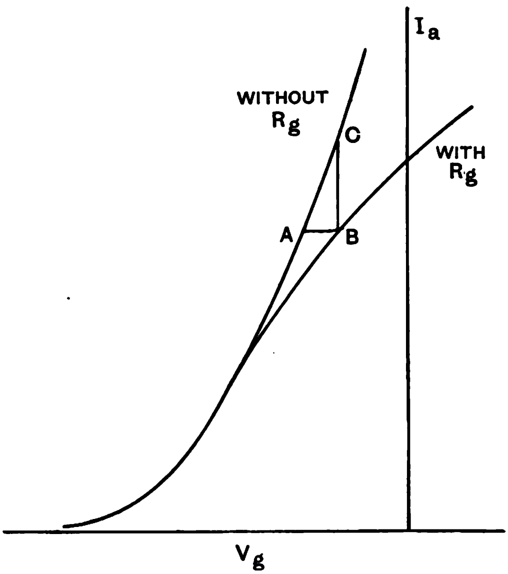


Fig. 3.

R_g by decreasing the grid potential by an amount AB. Hence $BC=\delta I_a$ and $AB=I_gR_g$. Calling the slope of the characteristic S, we have

$$S=\frac{BC}{AB}=\frac{\delta I_a}{I_gR_g}$$

and $$\frac{\delta I_a}{I_g}=S.R_g$$

This expression gives a measure of the increased sensitivity of the method, since δI_a is what is actually measured instead of I_g. Although it can be theoretically increased indefinitely by increasing R_g, great difficulties due to insulation are introduced if R_g is increased beyond about 50 megohms. This is sufficient, however, to give an increased sensitivity of about 10,000, thus enabling a grid current of about 10^{-10} amperes to be measured by means of a pointer instrument.

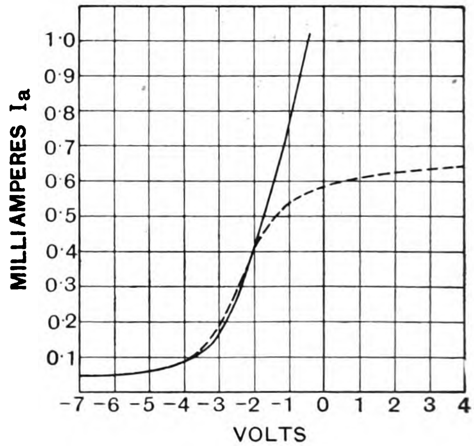


Fig. 4.

To plot the grid current characteristic a number of horizontal lines, such as AB in Fig. 3, are drawn corresponding to the grid voltage at A, the grid current is equal to AB/R_g and this is plotted on the vertical ordinate through the point A. If the valve contains gas it is known that grid current flows in the reverse direction for certain values of negative grid voltage owing to positive gas ions being attracted to the grid.

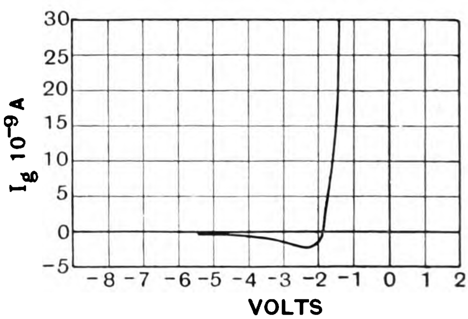


Fig. 5.

This will cause the grid to assume a higher or more positive potential than that indicated on V_g since the fall of potential in R_g is now in the reverse direction. This is seen in Fig. 4, which was obtained from tests on a soft valve; an analysis of these results in the way described above gives the grid characteristic shown in Fig. 5.

Grid Signal Characteristics and other Aids to the Numerical Solution of Grid Rectification Problems.

By W. A. Barclay, M.A.

PART I.

MOST experimenters are familiar with the use of the grid current characteristic of a valve in explaining the complicated theory of grid detection. Apart from this theoretical use, the usual practical function of the grid characteristic as applied to detector valves lies in the approximate determination of initial working conditions. Certain values of leak resistance and grid bias voltage being decided upon in more or less arbitrary fashion, a resistance line of position and slope to correspond is inscribed upon the conventional diagram, and its point of intersection with the characteristic curve noted. The co-ordinates of this point then represent the grid voltage and grid current of the system for initial or pre-signal conditions.

Thus far there is nothing at all questionable in the procedure, so long as the limitations which are tacitly imposed upon the diagram are distinctly understood. Unfortunately many amateurs (and valve manufacturers also) are apt to regard this diagram as conveying in some way an idea of the "detecting efficiency" of the valve. This efficiency, of course, is not only a function of the valve and the circuit in which it operates but depends also upon the magnitude of the signal which it is desired to rectify. The crux of the process of grid rectification lies in the change of mean grid potential due to the impressed signal, which, for simplicity in the argument, we shall assume to be pure C.W. Now, this change of mean grid potential for any signal is, as will be shown hereafter, readily obtainable from the characteristic diagram. Its value, however, is by no means ascertainable by mere inspection, and until it has been derived, the diagram affords no indication of "detecting efficiency." The idea that it is possible to estimate this solely from the "curvature" of the characteristic at the point of intersection with the resistance line is thus seen to be quite fallacious. Apart altogether from the fact that this point has to do with the initial conditions, and not with those under which signals are received, it should be noted that the term "curvature" as thus applied to the characteristic is quite unscientific. The idea in the minds of those who use the word in this connection is not the "curvature" of the mathematicians, but partakes of the nature of a second differential coefficient. The looseness of thought is reflected in the impossibility of exact definition, which, happily, there is no need to attempt.

The theory of grid rectification has been exhaustively dealt with in the pages of this journal, notably in the valuable series of articles by Mr. F. M. Colebrook (*E.W. & W.E.*, November, 1925—February, 1926) to which readers are referred. The writer, however, may be pardoned his impression that the quantitative aspect of the subject has not yet been developed on lines commensurate with its importance, and that from the point of view of the computer anxious for numerical results, the theory of grid detection is not in so satisfactory a state as the corresponding theory of amplification. For this, the complicated mathematics of grid detection is largely to blame: yet, in one view, this analysis can only be justified if, in the end, it smooths the way to an easy arithmetical or graphical procedure in the practical case. To simplify the calculations incidental to the subject has been the aim of the present writer in the following notes. At the outset, as much of the theory of grid detection will be considered as will render intelligible the conception of

"grid signal characteristics," after which, abandoning theory, practical methods of obtaining these curves both graphically and arithmetically will be discussed. Thereafter, certain advantages of these methods will be considered, always from the arithmetical standpoint, and graphical and arithmetical processes described which will materially shorten the calculations involved. It should be clearly realised, however, that the author's method of "grid signal characteristics" is applicable to grid characteristics of any form. It is thus eminently suited to the experimental curves met with in practice, which do not, generally, conform to the exponential form over a wide working range of grid voltage.

The theory of grid rectification being presumed familiar to readers, the conventional diagram of Fig. 1 will not require any detailed explanation. The i_g—v_g curve having been experimentally obtained for conditions in the valve, the line VP_o is drawn to show the relation between the current flowing and the P.D. between the two ends of the leak, of which that connected to the filament is held at the fixed potential v, represented by the point V. The pre-signal values of voltage and current are then shown by the co-ordinates of P_o, viz., OM_o and M_oP_o.

The problem of grid detection is, in general, to obtain the position of a point M_s which will represent the average value v_s of grid voltage during reception of a signal which we shall suppose of amplitude E. For the normal detecting circuit, the point M_s will generally be situated to the left of M_o. In Fig. 1 lengths LM_s and M_sN are taken to represent E volts, so that LQ and NR are the extreme limits of current variation. Now, during a sinusoidal variation in grid voltage $E \sin \omega t$ about a mean value represented by the point M_s, there will be a certain average value of current, mathematically determinable, which may be represented by a point P_s on the ordinate upon M_s. The length M_sP_s will, of course, depend upon the magnitude of E as well as upon the shape of the curve, so that for other values of signal amplitude, other positions of P_s will correspond on the same ordinate. If the signal amplitude E is such that the position of P_s happens to lie upon the leak line VP_o produced, it will be apparent that the average current flowing when $E \sin \omega t$ acts about M_s is exactly sufficient to maintain a P.D. represented by M_sV between the ends of the leak. In other words, if P_s lie on the leak line, M_s will represent the average voltage v_s of the grid during reception of a signal of amplitude E, using this particular value of leak and bias voltage. Further, the length M_oM_s will represent the amount of change in mean grid potential due to the reception of the signal, and this, of course, is our ultimate objective.

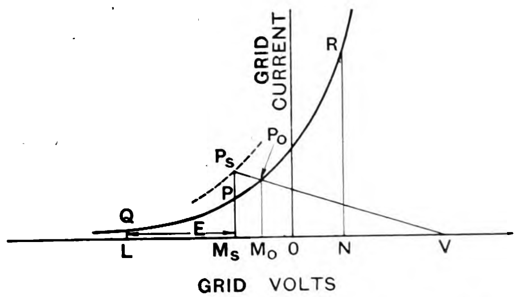


Fig. 1. *Conventional diagram for grid current characteristic.*

We have seen that by mathematical considerations (into which we shall enter presently) it is possible to assign the length of an ordinate M_sP_s which shall represent the average current corresponding to a sinusoidal variation of grid voltage of amplitude E about a mean value v_s. By repeating the same procedure for a different value of mean grid voltage, v_s', we can also obtain the ordinate $M_s'P_s'$ which represents the average current due to a sinusoidal variation of voltage of the same amplitude E about another mean position M_s'. It is clear that a series of ordinates may thus be plotted for different points along the voltage axis. Each such ordinate is derived from the original characteristic by determining mathematically the average grid current due to a sinusoidal variation in grid voltage of constant amplitude E, when the mean value of this signal voltage operates at various points of the voltage axis. To the curve drawn through the points P_s, P_s', etc., may be assigned the name of *the grid signal characteristic for signal amplitude E*. This is the dotted curve shown in Fig. 1. Its intersection with the leak line VP_o occurs at

P_s, and it is seen that, means having been found to draw the grid signal characteristic, the abscissa of its intersection with the leak line determines the mean value v_s of grid voltage during the signal in the same manner as the intersection of this line with the original grid characteristic determined the pre-signal conditions. In passing, it is to be noted that to every value of E there will correspond a separate grid signal characteristic curve. If a series of such curves for various values of E be drawn on the diagram, it becomes a simple matter to read off the variations in grid voltage due to the rectification of C.W. signals of various amplitudes, using any values of leak resistance and fixed bias voltage. This is possible inasmuch as the grid signal characteristics are entirely independent of leak resistance and bias voltage, depending solely upon the original grid characteristic curve and the signal amplitude. The derivation of the grid signal characteristics will now be considered.

Let the ordinary grid current characteristic of a valve as obtained experimentally be represented by the equation

$$i_g = f\,(v_g)$$

where f is, in general, an unknown function. If, now, the grid be maintained at a mean voltage value v_s, while subject to a sinusoidal variation of amplitude E, we may represent the total extent of the voltage variation by the distance LN, of which the middle point, M_s, represents the voltage v_s, while $LM_s=E$ volts (see Fig. 1). Let the frequency of the E.M.F. be n per second, so that the period of one complete oscillation is $1/n$ second. Let us consider the variation of grid voltage with the time during one complete oscillation. We shall suppose that at time $t=0$, the grid voltage has its minimum value, $v_s - E$, represented by the point L. At the end of a quarter period, or when $t=1/4n$, its value is v_s, represented by M_s. When $t=1/2n$, its value is v_s+E, shown at N. As t increases yet further, the voltage again diminishes, until at $t=1/n$ it is again represented by the point L. A convenient expression for the instantaneous grid voltage will be

$$v_g=v_s - E\cos 2\pi nt \qquad \ldots \quad (1)$$

as may be seen by substituting for the above values of t. The corresponding expression for the variation in grid current is at once given by

$$i_g=f\,(v_s - E\cos 2\pi nt) \qquad \ldots \quad (2)$$

As t assumes the values 0, $1/4n$, $1/2n$, $3/4n$, $1/n$, the values of i_g are represented by the ordinates LQ, M_sP, NR, M_sP and LQ. Our problem now is to find the height of an average ordinate, M_sP_s, which shall represent the average value of current, $\bar{\imath}$, throughout this cycle. As in half a period from $t=0$ the value of i_g passes from minimum to maximum, and in the next half period the cycle is reversed, the average current flowing through each half period is the same. We may therefore proceed to find the average value of i_g during the first half cycle only. This mean value is obtained by integrating equation (2) with respect to time between the limits $t=0$ and $t=1/2n$, and dividing by the amount of the time between these limits, viz., $1/2n$. We have then for the average value of the current,

$$\bar{\imath} = 2n\int_0^{\frac{1}{2n}} f\,(v_s - E\cos 2\pi nt).dt \qquad \ldots \quad (3)$$

or, changing the variable to θ, the angular phase of the voltage variation at instant t, so that $\theta = 2\pi nt$,

$$\bar{\imath} = \frac{1}{\pi}\int_0^{\pi} f(v_s - E\cos\theta).d\theta \qquad \ldots \quad (4)$$

The insuperable obstacle to the straightforward evaluation of this integral lies, of course, in the unknown nature of the function f. By assuming an exponential form for this function Mr. Colebrook has obtained the value of a similar integral as the sum of an infinite series, and has given tables by means of which it may be accurately computed under this hypothesis. But, as before remarked, the experimental curves obtained in practice rarely conform throughout any wide range of grid voltage to the exponential form, and it will be better, perhaps, to tackle the problem from a new angle, leaving the form of the function unspecified. The most obvious procedure, where the form of the function is unknown, is to have recourse to methods of approximate or "numerical" integration, and the writer applied various formulæ widely used in engineering and actuarial science to the problem of evaluating this integral. The most convenient for the

purpose, however, and one which, as will be shown, lends itself admirably to arithmetical processes, was found to be the following, due to Bronwin (*Phil. Mag.*, 34 (1849), p. 262),

$$\int_0^{\pi} f(\cos\theta).d\theta = \frac{\pi}{p}\left\{f\left(\cos\frac{\pi}{2p}\right)+f\left(\cos\frac{3\pi}{2p}\right)\right.$$
$$\left.+\ldots+f\left(\cos\frac{\overline{2p-1}.\pi}{2p}\right)\right\}$$

which is rigorously true if f is presumed to be a function whose $2p$th differences are zero.

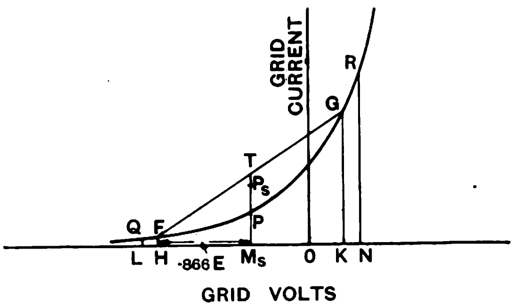


Fig. 2. *Showing the derivation of the point* P_s *on the grid signal characteristic corresponding to signal amplitude* E.

Assuming, then, that the sixth differences of our characteristic function are negligible throughout the voltage range in which we are interested, we may put $p=3$, and write,

$$\int_0^{\pi} f(\cos\theta).\,d\theta = \frac{\pi}{3}\left\{f\left(\cos\frac{\pi}{6}\right)\right.$$
$$\left.+f\left(\cos\frac{\pi}{2}\right)+f\left(\cos\frac{5\pi}{6}\right)\right\} \quad \ldots (5)$$

Here, then, is a very simple evaluation of the integral in equation (4). We have,

$$i = \frac{1}{\pi}\int_0^{\pi} f(v_s - E\cos\theta)\cdot d\theta$$
$$= \tfrac{1}{3}\left\{f\left(v_s - E\cos\frac{\pi}{6}\right)+f\left(v_s - E\cos\frac{\pi}{2}\right)\right.$$
$$\left.+f\left(v_s - E\cos\frac{5\pi}{6}\right)\right\}$$
$$= \tfrac{1}{3}\{f(v_s - .866E) + f(v_s)$$
$$+ f(v_s + \cdot 866E)\} \quad \ldots \quad (6)$$

If in Fig. 2 we take the points H and K on either side of M_s and distant from it by $.866E$, and erect ordinates HF and KG to the curve, it is evident that we can substitute the lengths of the three ordinates in equation (6). We have then the remarkable result,

$$i = M_sP_s = \tfrac{1}{3}\{HF + M_sP + KG\} \quad \ldots (7)$$

A very simple geometrical construction for obtaining the value of the average current thus follows which, for facility of reference, may be termed the "three-ordinate method." On either side of M_s (Fig. 2) at distances equal to $.866E$ erect ordinates HF and KG to the curve. Join FG, and let it meet the ordinate at M_s in T. Then the point P_s is situated above P at two-thirds the distance PT. For

$$M_sT = \tfrac{1}{2}(HF + KG)$$
$$PT = M_sT - M_sP = \tfrac{1}{2}(HF + KG - 2M_sP)$$

By construction

$$PP_s = \tfrac{2}{3}PT = \tfrac{1}{3}(HF + KG - 2M_sP)$$
$$\therefore M_sP_s = M_sP + PP_s = \tfrac{1}{3}(HF + KG + M_sP)$$

The procedure thus indicated to find the point P_s on the ordinate at M_s can, of course, be carried out very easily for any other value of mean voltage v_s, taking care that the extreme ordinates be always situated at the constant distance of $.866E$ volt from the centre ordinate. By this means, the grid signal characteristic curve corresponding to a given signal amplitude E may be plotted out as v_s varies in value. By an extension of the process, the signal characteristics for other values of E may also readily be found.

It may be useful here to outline a graphical adaptation of the three-ordinate process which the writer has found of service in plotting out the grid signal characteristics for various values of E. Let it be required, for example, to plot these curves for every .2 volt difference in E. In Fig. 3 let the voltage axis be divided into steps of $.2 \times .866$ volt, *i.e.*, of .173 volt, starting from any arbitrary position. Then, by applying the three-ordinate method, taking each ordinate in turn as the mean, and using three consecutive ordinates, the grid signal characteristic for $E = .2$ volt is obtained. By applying the method using the next ordinate but one on either side of every mean, we obtain the curve for $E = .4$ volt. Again applying it, using the third ordinate from every mean,

we obtain that for $E=.6$ volt. In the diagram (Fig. 3), chords C_1, C_2, C_3 have been drawn corresponding to these three cases for the particular ordinate at M. The corresponding points P_1, P_2, P_3 are shown at their appropriate positions on this ordinate between the chords and the curve. The dotted curves show the results of the application of the process to other ordinates. The constructional work may be done very rapidly in pencil, the resulting points on the signal characteristics being marked in ink. As large a scale as can conveniently be used is recommended for the work.

The above graphical method is not always, value of several sinusoidal E.M.Fs. of different amplitudes. If i_n represent the average value of current due to an alternating

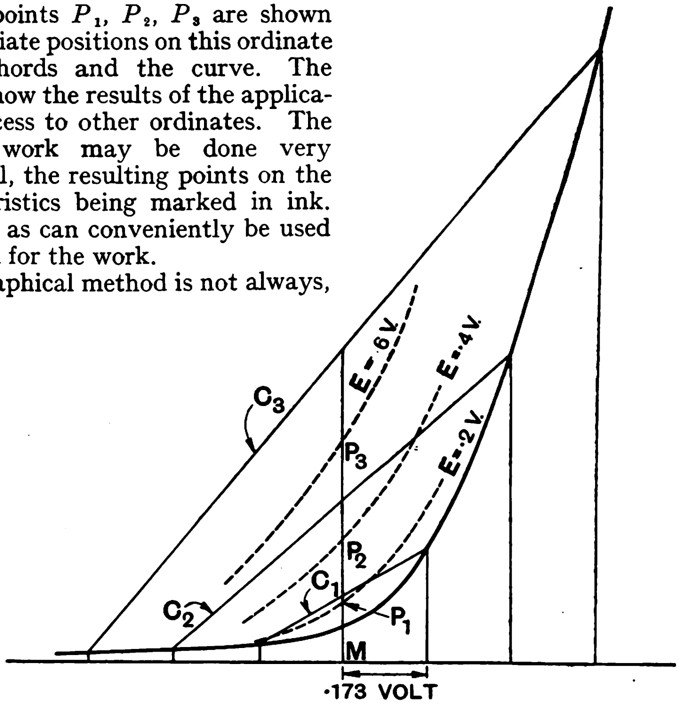


Fig. 3. *Graphical derivation of grid signal characteristic curves.*

however, convenient, and the arithmetical process now to be described may, perhaps, be considered superior to it from the point of view of accuracy. It being required to find the grid signal characteristics at intervals of e volt signal amplitude, set off on the voltage axis steps of $.866e$ volt on either side of the zero point (see Fig. 4). Then the values of grid voltage at these points will be $.866pe$, where p has a succession of integral values, positive or negative. Let the corresponding values of grid current for these values of p be denoted by i_p. Then we may write

$$i_p=f\,(.866pe) \quad \ldots \quad \ldots \quad (8)$$

Suppose, now, that we select some particular value of p which we will call n, so that the particular voltage on the grid is $.866ne$ and the corresponding grid current i_n. Let us consider this voltage $.866ne$ as the mean E.M.F. of amplitude e operating about a mean grid voltage $v_s=.866ne$, we have, since

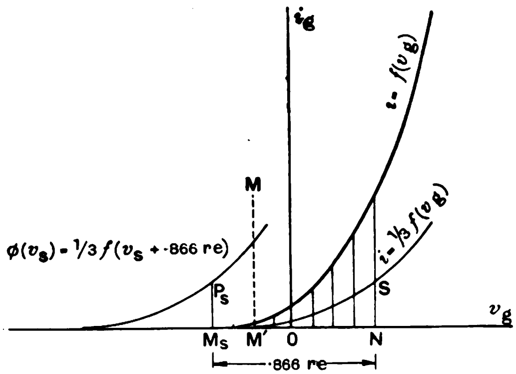


Fig. 4. *Each small division on the* v_g *axis represents* .866e *volts. In this diagram* M_s *is shown four divisions to the left of* O, *i.e., the value of* n *taken is* -4, *and* $v_s = -4 \times .866e$ *volts. The length* M_sN *occupies eight divisions, i.e.,* r = 8, *so that the signal amplitude illustrated is* 8e *volts.*

the consecutive ordinates are situated .866e volt apart, by equation (7),

$$ {}_{e}\bar{i}_n=\tfrac{1}{3}\{i_{n-1}+i_n+i_{n+1}\} $$

Also, if the signal amplitude is $2e$, the average current is, similarly,

$$ {}_{2e}\bar{i}_n=\tfrac{1}{3}\{i_{n-2}+i_n+i_{n+2}\} $$

And, generally, the average current due to a signal amplitude of re volts, operating at the value .866ne of mean grid voltage where n and r are any integers, is

$$ {}_{re}\bar{i}_n=\tfrac{1}{3}\{i_{n-r}+i_n+i_{n+r}\} \quad \ldots \quad (9) $$

On the diagram of Fig. 4 we may select any arbitrary ordinate MM', to the left of which all ordinates to the original grid characteristic curve may be considered negligible. If the value of n taken in the last paragraph is such as to cause the position of v_s to lie to the left of MM', *i.e.*, if the current ordinate i_n is negligible, the ordinates i_n and i_{n-r} may be put equal to zero in equation (9), which thus becomes

$$ {}_{re}\bar{i}_n=\tfrac{1}{3}i_{n+r} \quad \ldots \quad \ldots (11) $$

a result of extreme simplicity. Rewriting

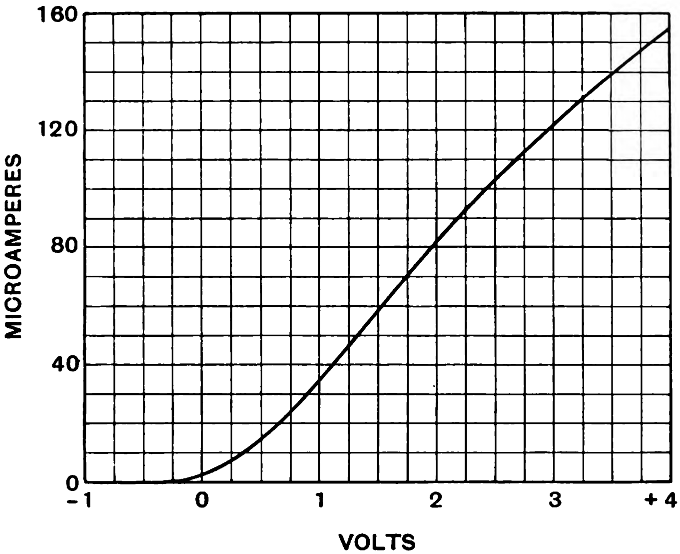


Fig. 5. *Grid current characteristic of Edison Swan D.R.2 valve.* (v_f = 2v ; v_a = 60 v.)

In computing these values, much labour will be saved if each of the original current values obtained from the characteristic be divided by 3. The values of ${}_{re}\bar{i}_n$ as both n and r vary may thus be easily obtained by simple addition. Writing $j_n=\tfrac{1}{3}i_n$, we have,

$$ {}_{re}\bar{i}_n=j_{n-r}+j_n+j_{n+r} \quad \ldots (10) $$

the values of which may be rapidly set down by inspection from a table of values of j_n.

It will often occur, in carrying out the addition process of the last paragraph, that the values of several of the ordinates dealt with are so small as to be negligible. Owing to this circumstance the task of plotting the grid signal characteristics over a portion of their length may be yet further facilitated.

this equation by means of (8),

$$ {}_{re}\bar{i}_n=\tfrac{1}{3}f\,(.866\,(n+r).e) \quad \ldots (12) $$

it appears that, for any position of mean grid voltage v_s=.866ne situated to the left of MM', a sinusoidal variation of re volts amplitude will cause to flow an average current equal to one-third of the instantaneous current shown by the original grid characteristic at a voltage increased by .866re. In other words, the grid signal characteristic of amplitude re is, for all that part of it situated to the left of the ordinate MM', a replica of the curve obtained by dividing the ordinates of the original grid characteristic by three, the horizontal distance between the two curves being equal to .866re (see Fig. 4).

This may perhaps be more clearly demonstrated by considering the average grid current flowing for signal amplitude re as a function of the mean grid voltage about which the signal operates. If v_s denote this mean voltage, we may write

$$_{re}\bar{i}_n = \phi(v_s)$$
$$= \phi\,(.866ne)$$

Therefore, from equation (12),

$$\phi\,(.866ne) = \tfrac{1}{8}f\,(.866\,(n+r).e)$$

i.e., $\phi\,(v_s) = \tfrac{1}{8}f\,(v_s + .866re)$ ... ... (13)

which is the analytical expression of the age. As in all cases the signal characteristics lie to the left of the original curve, it will be seen that the intersections of the leak line with the signal curves will mostly occur at values of grid voltage lying to the left of the line MM'. Thus it happens that, in the great majority of cases, only the signal characteristics to the left of MM' need be drawn, and it is a happy circumstance that it is in this region of the diagram that the curves are easiest to construct.

We shall now derive the grid signal characteristics for a typical case. Fig. 5 shows a grid characteristic curve supplied

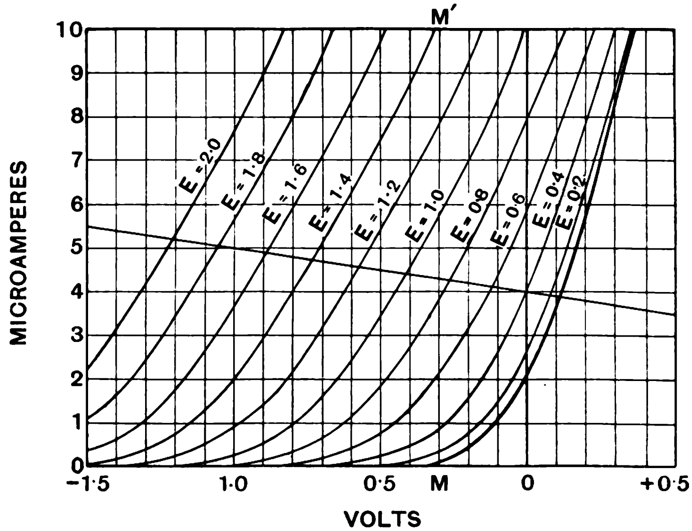


Fig. 6. *Portion of grid signal characteristics of D.R.2 valve. The leak line is that for 1 megohm with fixed positive bias of 4 volts.*

statement made above. It should be carefully noted that equations (11), (12) and (13) are only true for certain values of v_s, viz., those at which ordinates to the original characteristic may be considered as negligible. For values of v_s to the right of MM', the signal characteristics must be plotted from equations (9) or (10).

It will be convenient to recall here the purpose for which the grid signal characteristics are constructed. As we have seen, they are used in conjunction with the leak resistance line to determine the mean value of grid voltage under signal conditions in precisely the same way as the original grid characteristic determined the pre-signal voltage.

by the Edison Swan Company for their D.R.2 valve. Taking $e = .2$ volt, the values of i_n for the values $v_g = .866ne = .173n$ were read off this curve and tabulated as in the annexed table. Corresponding values of $_{re}i_n$ for various values of r were then computed as shown, and plotted against their particular mean voltage values $.173n$ in Fig. 6. The heavy curve in this figure is the original grid characteristic: the others represent the signal characteristics at intervals of .2 volt up to a signal amplitude of 2 volts. It will be seen that all curves to the left of MM' are similar.

The resistance line corresponding to a leak of 1 megohm at a positive bias of 4 volts is

also shown, from which the mean grid voltages for various signal amplitudes with this leak may be read off immediately. For other values of leak and bias voltage, other lines may be drawn as required.

It may be remarked that the writer's choice of a grid current characteristic to illustrate his method was purely fortuitous, and no expression of opinion as to its merits as "detector" is intended to be conveyed. The characteristic is, however, otherwise interesting, departing notably from the exponential form (Fig. 5).

In the next part of this paper it is hoped to deal with further simplifications in method and practical working.

TABLE

Showing derivation of values of $_{re}\bar{i}_n$ from those of i_n.

n	$v_g = .173n$	i_n	j_n	$\cdot 2\bar{i}_n$	$\cdot 4\bar{i}_n$	$\cdot 6\bar{i}_n$	$\cdot 8\bar{i}_n$	$1 \cdot 0\bar{i}_n$	$1 \cdot 2\bar{i}_n$	$1 \cdot 4\bar{i}_n$	$1 \cdot 6\bar{i}_n$	$1 \cdot 8\bar{i}_n$	$2 \cdot 0\bar{i}_n$
—9	—1.56	0	0	0	0	0	0	0	0	0	0.2	0.7	1.7
—8	—1.39	0	0	0	0	0	0	0	0	0.2	0.7	1.7	3.3
—7	—1.21	0	0	0	0	0	0	0	0.2	0.7	1.7	3.3	5.3
—6	—1.04	0	0	0	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3
—5	—0.87	0	0	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7
—4	—0.69	0	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7	
—3	—0.52	0	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7		
—2	—0.35	0	0	0.2	0.7	1.7	3.3	5.3	7.3	9.7			
—1	—0.17	0.6	0.2	0.9	1.9	3.5	5.5	7.5	9.9				
0	0	2.0	0.7	2.6	4.0	6.0	8.0	10.4					
+1	0.17	5.0	1.7	5.7	7.2	9.0							
+2	0.35	10.0	3.3	10.3									
+3	0.52	16.0	5.3										
+4	0.69	22.0	7.3										
+5	0.87	29.0	9.7										

NOTE.—In the above Table, the values computed for average grid current have an upper limit of 10 microamperes, as no higher values are required to plot the limited region shown in Fig. 6. In general, however, the Table should be extended to utilise a greater portion of the characteristic of Fig. 5 than is here done.

(To be continued.)

Alterations to the Modulating Panel at 2LO.

By E. Green, J. L. Hewitt, and T. G. Petersen.

THE original 2LO station was erected at Marconi House before the British Broadcasting Company was formed, and many investigations were made there by Marconi's Wireless Telegraph Company, Limited. Among these, an interesting investigation by Captain Round, in which one of the authors was assisting, of the conditions obtaining in the Modulating Panel of the station, gives a good example of the value of plate current-plate voltage characteristics in studying the action of valves.

The alterations made to the panel, as a result of the investigation, greatly improved the modulation by enabling a greater depth of modulation to be used over the whole frequency range, more especially at the highest frequencies. These alterations were subsequently embodied in the new 2LO station.

If the H.T. D.C. voltage $= V_0$

and the electrostatic voltmeter reading $= V$

then amplitude of voltage variation $= V \times \sqrt{2}.$

$$\text{Depth of modulation} = \frac{\sqrt{2} \,.\, V}{V_0} \times 100 \text{ per cent.}$$

We shall see later that this would give misleading results at the lowest frequencies, but would be approximately correct for all frequencies above 100 cycles.

At frequencies around 200 to 1,000 cycles, it was possible to modulate quite normally to a depth of 55 per cent. without getting grid current or rectification on the main modulator valves. As the frequency was raised, this possible depth gradually decreased until at a frequency of 5,000 cycles it was only about 30 per cent., and at 10,000, about 20 per cent. If these limits were exceeded, grid currents flowed in the main modulating

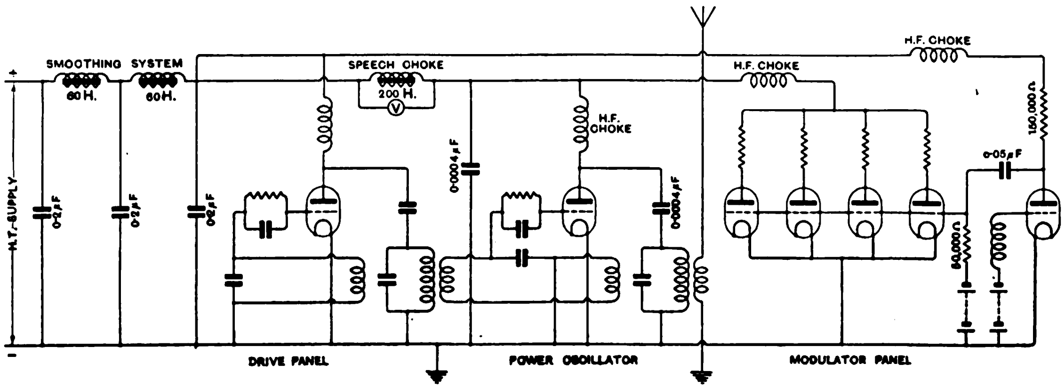


Fig. 1.

valves, and there was also rectification of plate current with consequent distortion.

An ingenious note oscillator was used by means of which a sinusoidal voltage could be applied of definite amplitude, and of any frequency up to 10,000 cycles or more, either to the grid of the sub-modulator valve or directly to the grids of the main modulator valves.

The percentage modulation was measured by means of an electrostatic voltmeter across the speech choke in the anode circuit of the valve.

It was found that this effect was due to the .001μF capacity which was virtually in parallel with the power oscillator, and by changing the main modulator valves, it was possible to obtain equal depth of modulation over the whole frequency range required.

The following is an outline of the investigation, and of the alterations made to the modulator panel as a result.

The schematic diagram of 2LO is shown in Fig. 1. In particular the main modulator panel as it then existed consisted of four M.T.7B valves in parallel, whilst the sub-modulator was one M.T.4B valve. (The

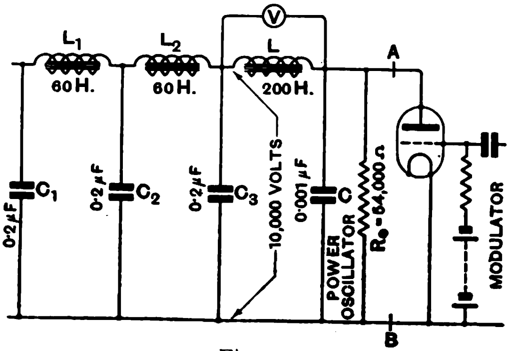


Fig. 2a.

plate-current, plate-voltage characteristics of the four M.T.7B valves are shown in Fig. 4, and those of the M.T.4B in Fig. 5(A.)

H.T. D.C. voltage=9,000.

Feed to power oscillator=167mA.

Total feed to four main modulator valves=160mA.

Feed to sub-modulator valve=10mA.

redraw the power oscillator and main control valves as shown in Fig. 2a. The capacity of 0.001μF in parallel with the 54,000 ohms is made up of the two 0.0004μF condensers that are shown as the blocking and feed condensers of the power oscillator in Fig. 1, and an estimated 0.0002μF due to stray capacity from the H.T. side of the system to earth. The voltmeter across the speech choke is an electrostatic one reading up to 5,000 volts.

As noted before, with no modulation on the set the grid bias on the main modulating valves is adjusted so that they take a total current of 160mA. This is the point O on the characteristic curves of Fig. 4. We require to find the locus of the working point when an alternating voltage is applied to the grids of the main modulating valves. The simplest possible and the ideal solution would occur if the speech choke had an infinitely large inductance, L, and the capacity across the equivalent resistance (54,000 ohms) of the power oscillator were zero. In this case the main modulating valves would be working into the resistance of 54,000 ohms, and the working line would be as shown at ROR' in Fig. 4. From this it will be seen that the theoretical limit of modulation without grid current would be

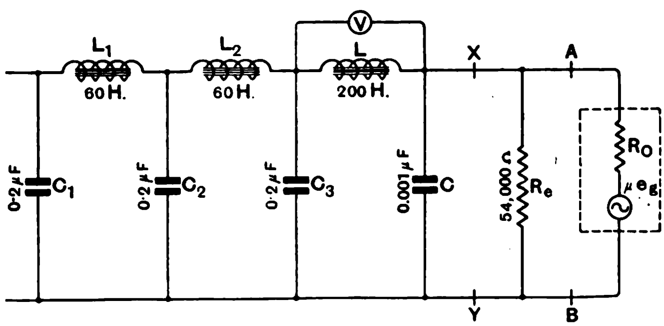


Fig. 2b.

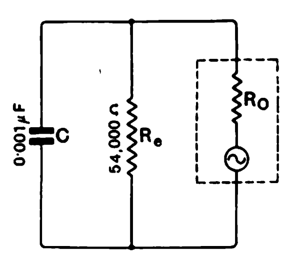


Fig. 2c.

The power oscillator circuit takes a feed proportional to the H.T. voltage. Hence it may be regarded as a resistance

$$=\frac{9{,}000}{0.167}=54{,}000 \text{ ohms,}$$

for the comparatively low frequencies at which the power to it is modulated by the main modulator valves. We can now

about 5,000 volts max. = 55 per cent. over the whole frequency range required.

The actual load into which the main modulating valves work is the whole complex circuit to the left of AB in Fig. 2a. It is well known that while working within the limits of the straight part of its characteristics a valve (or valves in parallel) can be replaced (so far as the action on the external circuit

is concerned) by an alternator of resistance R_0 and E.M.F. me_g,

where $R_0 = \left(\frac{d\,E_p}{d\,I_p}\right)_{E_g \text{ constant}}$ = slope resistance,

m = amplification factor,

and e_g = alternating grid E.M.F.

This has been done in Fig. 2b and serves to bring out more clearly the nature of the external load. We note the following points :—

1. With some very low frequency modulation, the speech choke "L" and the smoothing system, would be in tune and would form an acceptor circuit across the resistance R_e.

(NOTE.—The equivalent circuit of the whole smoothing system, as measured across the final condenser C_3, Fig. 2a, varies with the frequency. At very low frequencies, *e.g.*, 10 cycles, $1/C_1\omega$ or $1/C_2\omega$ is much greater than $L_1\omega$ or $L_2\omega$, and therefore the equivalent circuit may be regarded as approximately equal to C_1, C_2, C , all in parallel. At high frequencies $L_1\omega$ and $L_2\omega$ are very much greater than $1/C_1\omega$ or $1/C_2\omega$ and the equivalent circuit is therefore approximately equal to the condenser C_3.)

To continue, if we consider C_1, C_2, and C_3 in parallel to be equivalent to the smoothing system, the resonant frequency n mentioned above will occur when

$$L\omega = \frac{1}{(C_1 + C_2 + C_3)\,\omega}$$

$$\text{Therefore } n = \frac{1}{2\pi\sqrt{L(C_1 + C_2 + C_3)}}$$

Taking $L = 200$ henries

and $C_1 = C_2 = C_3 = 0.2\mu\text{F}$

we get :—

$$n = \frac{10^3}{2\pi\sqrt{120}} = \underline{\underline{15 \text{ cycles per sec. (approx.)}}}\text{*}$$

With an alternating voltage of this frequency on the grid, we should get a large voltage reading across the speech choke † although there was actually no alternating current flowing through R_e, *i.e.*, no modulation of the current supplied to the power oscillator.

TABLE OF REACTANCE OF L AND $C_1+C_2+C_3$ AT VARIOUS FREQUENCIES.

Frequency cycles per second.	Reactance of L $= L\omega$	Reactance of $C_1+C_2+C_3$ $= \frac{1}{(C_1+C_2+C_3)\omega}$	Reactance of L and $C_1+C_2+C_3$ $= L\omega - \frac{1}{(C_1+C_2+C_3)\omega}$
5	6,280	53,100	— 46,820
10	12,560	26,550	— 13,990
15	18,850	17,700	+ 1,150
20	25,100	13,270	+ 11,830
25	31,400	10,600	+ 20,800
30	37,700	8,840	+ 28,860
40	50,200	6,640	+ 43,560
50	62,750	5,300	+ 57,450
60	75,400	4,420	+ 70,980
80	100,400	3,320	+ 97,080
100	125,600	2,650	+122,950

From the above table we see that as the frequency is increased, a point is soon reached where the reactance

$$\left(L\omega - \frac{1}{(C_1 + C_2 + C_3)\omega}\right)$$

of the path through the speech choke and smoothing condensers becomes large compared with R_e (54,000 ohms) and so most of the modulated current will flow through R_e as required.

During this period the resultant load on the main modulating valves consists of R_e and an inductive reactance in parallel with it. The working line therefore becomes an ellipse traversed in the clockwise direction.

2. As the modulating frequency is further increased the next critical point occurs when the capacity C (0.001μF) resonates with the remainder of the circuit to the left of it, to form a rejector circuit between the points XY (Fig. 2b). This point will occur when

$$L\omega - \frac{1}{C_3\omega} = \frac{1}{C\omega}$$

As $1/C_3\omega$ is very small compared with $L\omega$ in the region of the resonant frequency, the critical point will occur approximately when $L\omega = 1/C\omega$.

* It has since been found that this resonant frequency is considerably higher, and C_3 has been increased to reduce it.

† There is a corresponding voltage across C_3 which acts on the drive and sub-modulator, giving complex effects.

If $L = 200$ henries and $C = 0.001\mu F$, we get :—

$$L\omega = \frac{1}{C\omega} \therefore n = \frac{1}{2\pi\sqrt{LC}}$$

$$\therefore n = \frac{10^4}{2\pi\sqrt{20}} = 356 \text{ cycles per sec.}$$

At this frequency practically no alternating current will flow to the left of XY, and the load on the main modulating valves is solely the resistance R_e. Thus the working line on the E_p I_p diagram is $A'OC'$, the line drawn for the simple case.

The working line at this frequency (5,000 cycles) and range (5,000 volts) is the ellipse $A'DC'B$ shown in Fig. 4, traversed in the counter-clockwise direction ; while at 10,000 cycles it is the ellipse $EHGF$. The detailed construction of these ellipses is given in Appendix I. It is clear from the figure that such ellipses would result both in grid current and in rectification, and owing to these effects the possible range of modulation at these higher frequencies would be greatly decreased, as found experimentally.

The ellipse for 10,000 cycles and a voltage

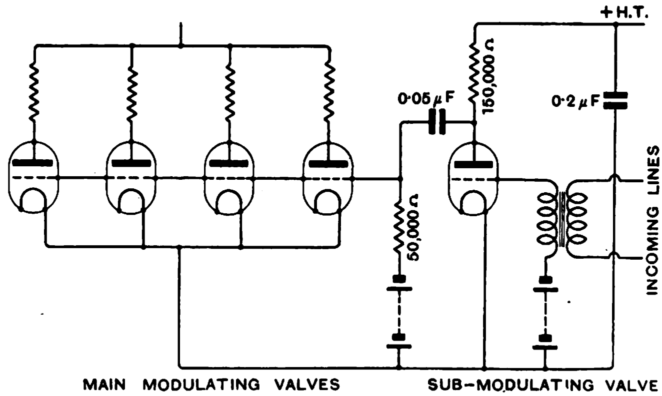


Fig. 3a.

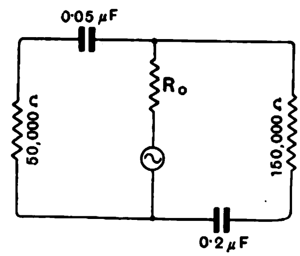


Fig. 3b.

3. At higher modulating frequencies, the capacity effects predominate, and the circuit becomes virtually that of Fig. 2c. The total capacity in parallel with R_e is made up of :—

Blocking and feed condensers	$= 0.0008\mu F.$
Stray capacity	$= 0.0002\mu F.$
Total capacity	$= 0.001\mu F.$

The working line on the E_p I_p diagram is again an ellipse, but this time traversed in the counter-clockwise direction. We will now proceed to study this in greater detail.

If we assume a voltage variation of 5,000 at the terminals of R_e we have :—

Maximum value of alternating current through R_e

$$= \frac{5,000 \times 1,000}{54,000} = 92\text{mA.}$$

At 5,000 cycles the maximum current through the capacity of $0.001\mu F$

$$= \frac{5,000 \times 2\pi \times 5,000 \times 10^3}{10^9} = 157\text{mA.}$$

amplitude of 2,000 is shown dotted in Fig. 4. This represents a modulation of 20 per cent., and would be about the limit for modulation at this frequency under the conditions shown. It could perhaps be increased to 25 per cent. by working at a lower H.T. voltage with correspondingly heavier currents in the main modulator. This would move the ellipse upward and to the left, and so keep it within the limits as to zero grid current and rectification.

It should here be pointed out that provided the ellipses are not too pronounced, and keep within the region of straight characteristics and zero grid current, there is no appreciable distortion. There is a phase shift between the modulated current flowing through R_e (the power oscillator) as compared with grid E.M.F. on the main modulating valves, and this phase shift varies with the frequency. The ear, however, takes no account of the phase relationship of the harmonic components of complex sounds, but only of their relative amplitudes. It may be seen

from Fig. 4 that the amplitude of grid E.M.F. required to give an amplitude of 5,000 volts across R_e increases only slightly up to a frequency of 10,000 cycles.

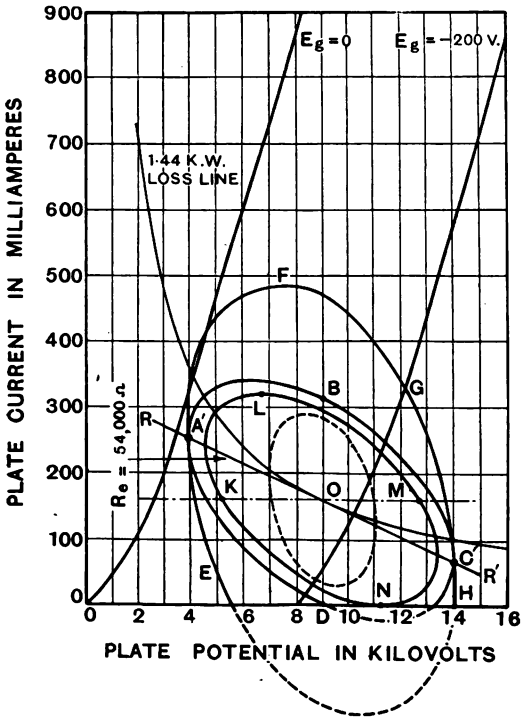


Fig. 4.

It is not possible to reduce the shunt capacity of $0.001\mu F$ to any great extent. It was seen that if the working ellipses could be moved up by allowing the control valves to absorb more power, and at the same time the I_p-E_p characteristics were made steeper by using valves of lower slope resistance R_o, it would be possible to maintain a much greater percentage modulation throughout the whole frequency range. Capt. Round therefore designed a new type of main modulating valve (known as the M.T.9A) capable of dissipating 600 watts each at the anode. Four of these were used in parallel and the power dissipated in them adjusted by grid potential to 2.4kW. The E_p-I_p characteristics of the four valves in parallel are given in Fig. 6. The slope resistance R_o for four of these valves in parallel is 2,500 ohms as compared with 7,000 ohms for four M.T.7B's in parallel.

The other adjustments of the set, after the improvements were carried out, were as follows :—

H.T. voltage = 8,000.

Feed to power oscillator = 188mA.

Equivalent resistance of power oscillator

$$R_e = \frac{8,000}{.188} = 42,600 \text{ ohms.}$$

Feed to main modulator valves = 300mA.

Grid potential of modulator valves

$$= -530 \text{ volts.}$$

The working line when R_e only is considered is AOC', and gives a possible range of modulation of 6,000 volts, and this can be maintained up to a frequency of 5,000 cycles, even with $0.001\mu F$ shunt capacity. The percentage modulation

$$= \frac{6,000}{8,000} \times 100 = 75 \text{ per cent.}$$

In Fig. 6 are also given the ellipses for a modulation voltage amplitude of 5,000 and frequencies of 5,000 and 8,800 respectively.

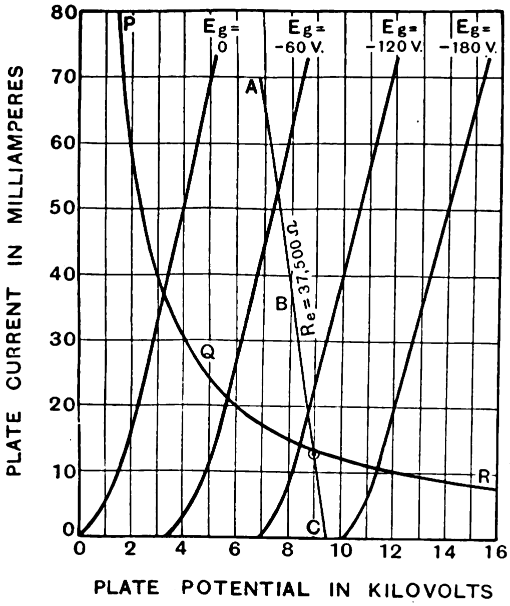


Fig. 5a.

It will be seen that this range of modulation ($62\frac{1}{2}$ per cent.) can just be obtained at the higher frequency. This is a striking improvement on the old conditions in which the possible modulation at 8,800 cycles

frequency and with $0.001\mu F$ shunt capacity would be only about half this value, as can be seen from Fig. 4.

The best value for the H.T. voltage and the point to which the modulating valves

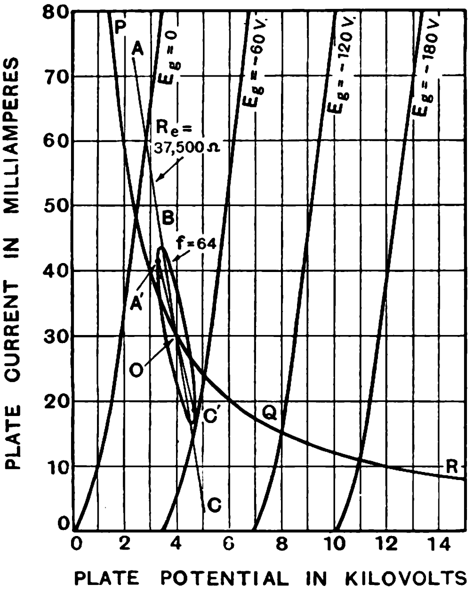


Fig. 5b.

are adjusted by grid potential, can be found by drawing out the various possibilities on the E_p-I_p characteristics.

The conditions to be fulfilled are that the power supplied to the power oscillator should not be more than 1.5kW, and that to the main modulating valves not more than 2.4kW.

In Fig. 7 are shown ellipses worked out for a frequency of 5,000, and modulated voltage amplitude of 5,000 for three values of H.T. voltage, viz., 6,000, 8,000, and 10,000. The conditions of 1.5kW to the oscillator and 2.4kW to the modulator are fulfilled in each case. The former condition implies that the equivalent resistance, R_e, of the power oscillator varies inversely as the square of the H.T. voltage in use, and this affects the slope and shape of the corresponding ellipse. (NOTE.—This variation in R_e can be obtained by alteration in the aerial coupling.)

It will be seen that with the H.T. voltage set at 8,000 the ellipse is most evenly situated between the working limits, and 8,000 volts was therefore the value chosen.

Alterations to Sub-Modulator System.

From Fig. 6 we see that the necessary grid bias on the M.T.9A valves is about 530 volts. This value is therefore the maximum value of grid swing to be provided from the sub-modulating valve system.

A diagrammatic representation of the sub-modulator system is given in Fig 3a. To study its action with alternating currents, we substitute the equivalent alternator and omit the H.T. D.C. and grid battery, and so derive Fig. 3b. From this we see that the external load on the valve consists of two parallel branches, one containing a resistance of 50,000 ohms, and a condenser of $0.05\mu F$ in series, and the other a resistance of 150,000 ohms and a condenser of $0.2\mu F$ in series. At a frequency of 127 cycles we have :—

Reactance $1/C\omega$ of $0.05\mu F$ condenser

$$= \frac{10^8}{5 \times 2\pi \times 127} = \underline{\underline{25{,}000 \text{ ohms.}}}$$

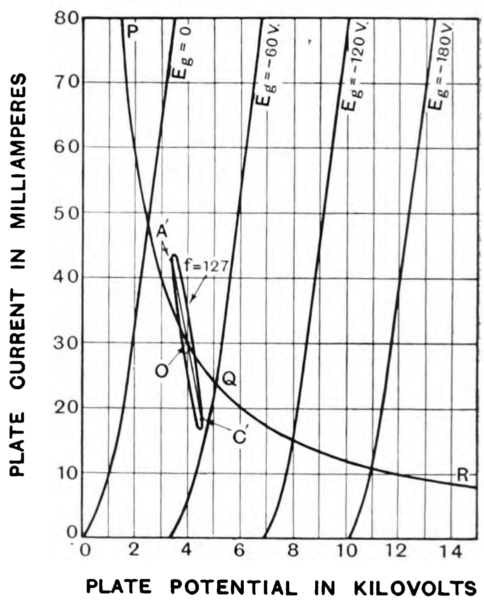


Fig. 5c.

Reactance of $0.2\mu F$ condenser

$$= \frac{10^7}{2 \times 2\pi \times 127} = \underline{\underline{6{,}250 \text{ ohms.}}}$$

(At higher frequencies these reactances will be proportionately smaller.)

At this frequency (which may be taken as near the lower limit to be dealt with) the

left hand branch is markedly capacitative, whilst the right hand branch is almost purely resistive since 150,000 ohms is much greater than 6,250 ohms. At higher frequencies the

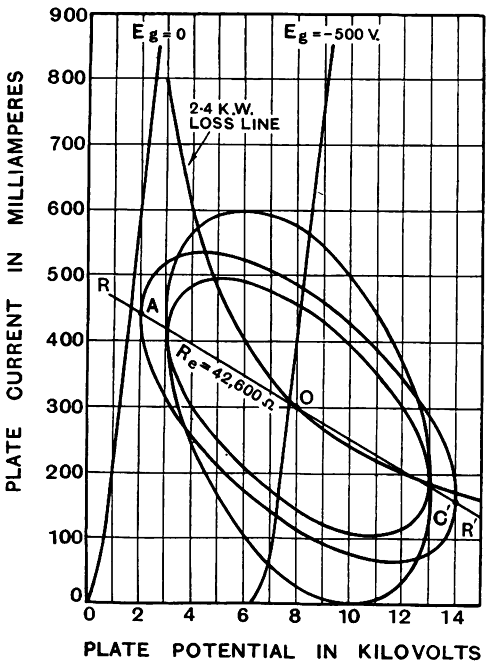


Fig. 6.

capacitative reactances are proportionately smaller, and the external load approximates to 50,000 ohms and 150,000 ohms in parallel which = 37,500 ohms.

The ellipse representing the capacitative load at 64 cycles and an amplitude of 500 volts across the 50,000 ohms is calculated in the appendix. In Fig. 5a are shown the I_p-E_p characteristics for one M.T.4B valve, which was originally used as the sub-modulator valve. The curve *PQR* represents the 120 watts loss line, the safe limit for the valve. The mean working point must not lie above this line. *ABC* is a line representing the external load of 37,500 ohms. The valve took 13mA at 9,000 volts with the grid bias used when the four M.T.7B's were the main modulating valves. These only required a maximum grid swing of about 180 volts, which could be provided at this setting with little distortion, since only a small range of the valve characteristics was used. For the four M.T.9A's, however, we saw that we required a maximum grid swing of 500 volts, and it was not possible to obtain this from a single valve. Capt. Round therefore put two M.T.4B valves in parallel as the sub-modulator system. The characteristics of these are shown in Fig. 5b, together with the working line *ABC*, for the external load of 37,500 ohms and the ellipse for the external load at 64 cycles. This ellipse is drawn the size required to give a maximum swing of 500 volts on the grids of the main modulating valves. This has been placed in the best position on the valve characteristics, from which we see that the grid bias should be —37 volts and the actual plate voltage 4,000 volts. The H.T. D.C. supply is at 8,000 volts, and the feed to the valves is 30mA; hence, the resistance in series with the anodes should be 133,000 ohms. The ellipse for a frequency of 127 and an amplitude of 500 volts across the 50,000 ohms is also shown in Fig. 5c.

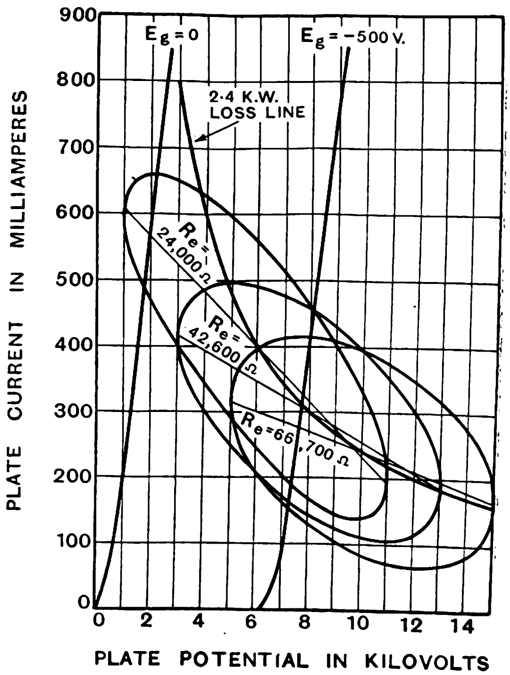


Fig. 7.

The conditions that arise in the last stages of audio frequency amplification for extra loud-speakers might be studied on the same lines with advantage, to see whether capacity or inductance effects are limiting the power that can be obtained without distortion.

APPENDIX I.

Calculation of Ellipses for the Various Cases.

Throughout these calculations we shall take the positive direction of the I—E axes as shown in Fig. 8a, as these are the positive directions of current and voltage for the load R_e when we wish to place the ellipse on the I_p-E_p valve characteristics. The scales of I and E are the same as those used in plotting the valve characteristics of Figs. 4, 6 and 7, so that the ellipse can be transferred without alteration in shape or size.

Fig. 8 (not used).

Example I.

Resistance of 54,000 ohms in parallel with a capacity of $0{\cdot}001\mu$F.

Amplitude of A.C. voltage = 5,000.

Frequency of A.C. voltage = 5,000.

First to determine the resistance line (see Fig. 8a: Mark off OA = 5,000 volts. For this amplitude of voltage the amplitude of current through R_e will be

$$\frac{5{,}000 \times 1{,}000}{54{,}000} \text{ mA} = 92\text{mA}.$$

Therefore draw AA' perpendicular to OA with AA' = 92mA. The straight line OR through O and A' is the resistance line required.

Secondly, we have to determine the ellipse for the capacity alone.

$$\text{Capacity reactance} = \frac{1}{C\omega} = \frac{10^6}{\cdot 001 \times 2\pi \times 5{,}000} = \underline{\underline{32{,}000 \text{ ohms.}}}$$

$$\text{The maximum capacity current} = \frac{5{,}000 \times 1{,}000}{32{,}000} = \underline{\underline{156\text{mA.}}}$$

Make OB and OD along the I axis each equal to 156mA, and $OC = OA$ = 5,000 volts.

Then A, B, C and D are points on the capacity ellipse.

Four more points on this ellipse can be found as follows: Since the capacity current leads the applied voltage by 90° we can write for the current and voltage at any particular instant,

$$i = I_{(max.)} \sin \omega t.$$

$$e = E_{(max.)} \cos \omega t.$$

When $\omega t = 45°$, $\sin \omega t = \cos \omega t = .707$.

So that $i = .707\, I_{(max.)}$ when $e = .707 E_{(max.)}$

This relation gives us four more points (F, G, H, and K) on the ellipse, and we can draw a curve freehand through the eight points found, which will be sufficiently accurate for our purposes.

$$LF = LG = NK = NH = {\cdot}707\, I_{(max.)} = ({\cdot}707 \times 156) = \underline{\underline{110 \text{ mA.}}}$$

$$PF = MG = PK = MH = {\cdot}707\, E_{(max.)} = ({\cdot}707 \times 5{,}000) = \underline{3{,}535 \text{ volts.}}$$

The resultant ellipse for the resistance and capacity in parallel is obtained by adding the corresponding instantaneous currents in the resistance and the capacity. Draw a line $QSTU$ parallel to OI cutting the ellipse in Q and U, and the resistance line in T.

Make $TV = SU$ and $TW = SQ$.

Then for voltage OS the resultant current is $ST + SU = SV$ or $ST - SQ$ (which is negative) $= SW$.

V and W are therefore points on the resultant ellipse, and others can be found in a similar way.

From an examination of this ellipse we can, however, find a more direct way of plotting it. (Fig. 8b.)

The resistance line ROR' is drawn as before and $OA = OC = E_{(max.)}$ = 5,000 volts (in this case).

If AA' and CC' parallel to OI cut ROR' in A' and C', then A' and C' are points on the resultant ellipse.

Also, if $OB = OD$ = maximum value of capacity current = 156mA (in this case), B and D are also on the resultant ellipse.

Four more useful points to determine are :—

1. The two points at which the current has its maximum value;

2. The two points at which the current passes through its zero value.

The vector diagram for the circuit is shown in Fig. 8c where

$OE = E_{(max.)}$ and represents the applied volts.

$OI_R = E_{(max.)}/R$ in phase with OE, represents current through the resistance.

$OI_C = E_{(max.)}/X = E_{(max.)}\, C\omega$ (in this case) and leads OE by 90°.

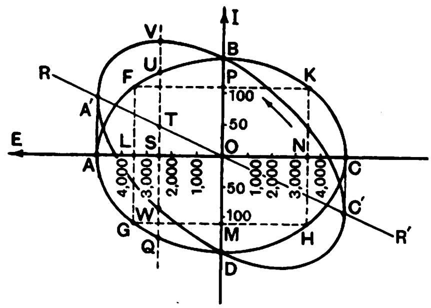


Fig. 8a.

The resultant current is therefore represented by $OI = \sqrt{OI_R^2 + OI_C^2}$ leading OE by an angle "θ" for which $\tan \theta = R/X$,

$$\cos \theta = \frac{X}{\sqrt{R^2 + X^2}} \quad \text{and} \quad \sin \theta = \frac{R}{\sqrt{R^2 + X^2}}$$

Now

$$OI = \sqrt{(E/R)^2 + (E/X)^2} = E\frac{\sqrt{R^2 + X^2}}{R\,.\,X}$$

= maximum value of resultant current.

When this occurs the instantaneous value of the voltage is

$$E_{(max.)} \cos\theta = E_{(max.)}\frac{X}{\sqrt{R^2 + X^2}}$$

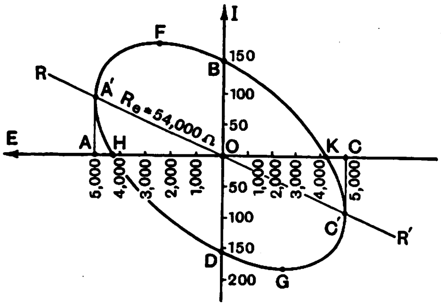


Fig. 8b.

Also, when the current is zero, the voltage

$$= E_{(max.)} \sin\theta = E_{(max.)}\frac{R}{\sqrt{R^2 + X^2}}$$

$$R = 54{,}000 \text{ ohms.}$$

$$X = 1/C\omega = 32{,}000 \text{ ohms.}$$

$$\sqrt{R^2 + X^2} = 62{,}800$$

Then for the points mentioned under (1) we have :

$$I_{(max.)} = \frac{5{,}000 \times 62{,}800 \times 1{,}000}{54{,}000 \times 32{,}000} = \underline{\underline{182\text{mA}}}$$

$$\text{when the voltage} = \frac{5{,}000 \times 32{,}000}{62{,}800} = \underline{\underline{2{,}550 \text{ volts.}}}$$

These results fix the positions of the two points F and G in Fig. 8b. For the points mentioned under (2) we have :—

Instantaneous current = 0

,, voltage $= E_{(max.)}\dfrac{R}{R^2 + X^2}$

This gives us the two points H and K in Fig. 8b. We can now draw the resultant ellipse through the points A', H, D, G, C', K, B, F, and A', remembering that the curve is tangential to AA' and CC', and parallel to ROR' at B and D.

The ellipse thus found is $A'BC'D$ of Fig. 4 in the main part of the article, and the ellipse for 10,000 cycles is also obtained in the same way.

Example II.

Fig. 9a shows the simplified diagram of the sub-modulator circuit. The external circuit consists of two branches in parallel. These are :—

1. 150,000 ohms (approximately, as the capacitative effect is negligible. See page 473 of main part of article).
2. 50,000 ohms in series with a capacity of 0·05μF.

At a frequency of 64 cycles ($\omega = 400$)

$$X = 1/C\omega = \frac{10^8}{5 \times 400} = 50{,}000 \text{ ohms capacitative}$$

reactance.

Probably the simplest method of finding the equivalent ellipse for this arrangement would be to find the resistance and capacity in parallel that would represent the left-hand branch. This is easily done by the graphical method given by F. M. Colebrook in his article "The Graphical Analysis of Composite Impedances," in *E.W. & W.E.*, Vol. II., No. 15, December, 1924. The construction as applied to this case is as follows :—

Draw OC (to scale) $= R = 50{,}000$ ohms (Fig. 9b).

Draw $CD = X = 50{,}000$ ohms at right angles to OC. Join OD.

Draw OP at right angles to OC and produce OC to a convenient length OQ. Draw AB at right angles to OD, cutting OP and OQ in A and B respectively. Then $OA = X' =$ the required capacitative reactance (to scale), and $OB = R' =$ the required resistance. We find that :—

Parallel resistance $R' = 100{,}000$ ohms.
Capacitative reactance $X' = 100{,}000$ ohms.

100,000 ohms and 150,000 ohms (right-hand branch) in parallel = 60,000 ohms. The complete circuit is therefore equivalent to 60,000 ohms resistance in parallel with 100,000 ohms capacitative reactance, and the equivalent ellipse can then be calculated as in Example I. :—

We require 500 volts across the 50,000 ohms, *i.e.*, 500 volts applied to the grids of the main modulating

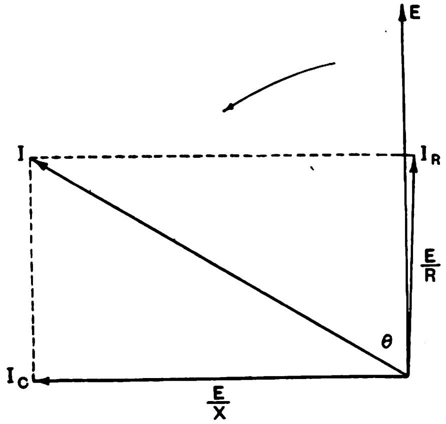


Fig. 8c.

valves. Now at 64 cycles we found that the reactance of the 0·05μF condenser was 50,000 ohms, and the resistance in the left-hand branch is also 50,000 ohms (Fig. 9a). The maximum voltage drops are therefore equal across the condenser and resistance, but in quadrature (Fig. 9c). Hence the

resultant voltage required across AB (Fig. 9a) will be :—

$$(500 \times \sqrt{2}) = \underline{707 \text{ volts}}.$$

$R = 60{,}000$ ohms.

$X = 100{,}000$ ohms $\sqrt{R^2 + X^2} = 116{,}700$ ohms.

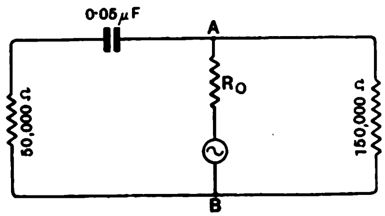


Fig. 9a.

In Fig. 9a (lettering as 8b) ROR' is the 60,000 ohms resistance line.

$$OA = OC = 707 \text{ volts}.$$

$$AA' \text{ and } CC' = \frac{707 \times 1{,}000}{60{,}000} = \underline{11 \cdot 8\text{mA}}.$$

Then $A'OC'$ is the resistance line and A' and C' are points on the required ellipse.

$OB = OD$ = max. value of capacity current

$$= \frac{707 \times 1{,}000}{100{,}000} = \underline{7 \cdot 07\text{mA}}.$$

B and D are points on the ellipse.

The resultant current is zero when voltage

$$= E_{(max.)} \frac{R}{\sqrt{R^2 + X^2}} = \frac{707 \times 60{,}000}{116{,}700} = \underline{364 \text{ volts}}.$$

This determines H and K.

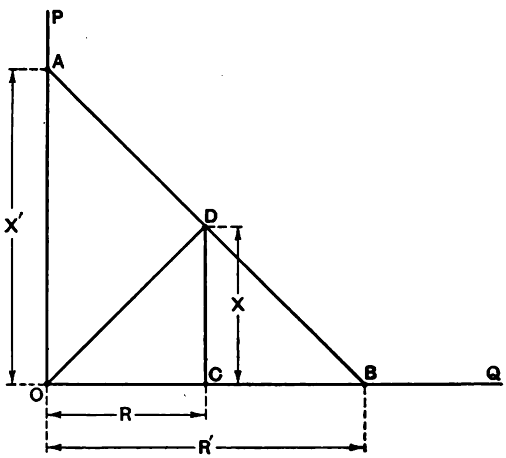


Fig. 9b.

Maximum resultant current

$$= E \cdot \frac{\sqrt{R^2 + X^2}}{RX} = \frac{707 \times 116{,}700 \times 1{,}000}{60{,}000 \times 100{,}000}$$
$$= \underline{13 \cdot 7\text{mA}}.$$

Voltage for maximum resultant current

$$= E_{(max.)} \frac{X}{\sqrt{R^2 + X^2}} = \frac{707 \times 100{,}000}{116{,}700} = \underline{606 \text{ volts}}.$$

This determines F and G and the ellipse may now be drawn.

As the frequency is increased this ellipse becomes narrower, and above 300 cycles the simple resistance line will show all that is required.

Example III.

Another method of obtaining the ellipse for the circuit shown in Fig. 9a is similar to that used in Example I., the various steps being as follows :—

Considering the left-hand branch of the circuit :

(1) Obtain the resistance line.

(2) Plot the ellipse for the capacity alone.

(3) Add (1) to (2) thus obtaining resultant ellipse for the left-hand branch. (NOTE.—Add instantaneous *voltages*, as current is the same through the resistance and capacity at any instant. (*Series* circuit) Ellipse shears *horizontally*.)

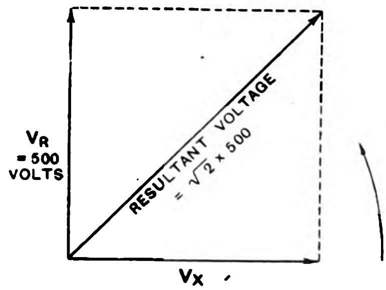


Fig. 9c.

(4) Obtain the resistance line for the right-hand branch.

(5) Add (3) to (4) thus obtaining the resultant ellipse for the whole circuit. (NOTE.—Add instantaneous *currents* as now the voltage is the same, at any instant, across the right-hand and left-hand branch. *Parallel circuit.* Ellipse shears *vertically*.)

The result (Fig. 10) should be the same as obtained in Example II. (Fig. 9d).

As before, we require 500 volts across the 50,000 ohms.

Frequency = 64 cycles.

Current in left-hand branch

$$= \frac{500 \times 1{,}000}{50{,}000} = \underline{10\text{mA}}.$$

(1) Mark off OA = 500 volts (Fig. 10). Draw AA' perpendicular to OA with AA' = 10mA. The straight line ROR' through O and A' is the resistance line required.

(2) Maximum current through the ·05μF condenser = 10mA. Make OB and OD along the I axis each equal to 10mA and $OC = OA$ = 500 volts. Then A, B, C, and D are points on the capacity ellipse.

As before, $i = 0{\cdot}707\ I_{(max.)}$ when $e = 0{\cdot}707\ E_{(max.)}$ This relation gives us the four points F, G, H, and K, as in Example I. The ellipse for the capacity alone may now be drawn through the eight points found.

(3) Adding (1) to (2) as previously explained we get the resultant ellipse $LMNP$ for the left-hand branch of the circuit.

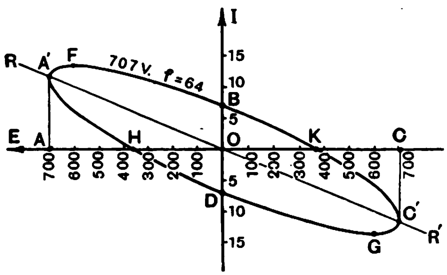


Fig. 9d.

(4) As before, in order to obtain 500 volts across the 50,000 ohms in the left-hand branch, we require 707 volts across AB (Fig. 9a), that is, we require 707 volts across the 150,000 ohms. Therefore the maximum current through this resistance is equal to

$$\frac{707 \times 1{,}000}{150{,}000} = 4{\cdot}7\text{mA}.$$

In Fig. 10, $OQ = OS = 707$ volts.
$QT = SU = 4{\cdot}7$mA.

TOU is therefore the resistance line for the right-hand branch of the circuit.

(5) Adding (3) to (4) we get the resultant ellipse $VMWP$ for the whole circuit which is the same as obtained in Fig. 9d.

APPENDIX II.

Power Relations in Oscillator and Modulator Circuits when using Choke Control.

In the article on I_p-E_p characteristics published in *E.W. & W.E.*, page 475, August, 1926 we saw that the maximum modulated power delivered from the modulators to the power oscillator was about 300 watts. This is in addition to the steady power that is supplied to the power oscillator when there is no modulation. But with choke control the H.T. D.C. power supplied from E (Fig. 11) is the same whether modulation is occurring or not. It follows that the power dissipated in the anodes of the modulators is decreased by the amount of modulated power supplied to the power oscillator. It is interesting to study in detail how this occurs. A simplified diagram of the circuit is shown in Fig. 11.

Let H.T. voltage of supply $= E$.
Steady current to power oscillator $= I_0$
Steady current to modulators $= I_M$

These are represented by the three horizontal lines in Fig. 12.

Then power to oscillator $= EI_0$
Power to modulators $= EI_M$
Total power $= E\ (I_0 + I_M)$

When a voltage varying as $\sin\ \omega t$ is applied to the grids of the modulators their plate current will have a varying component which may be written as $kI_0 \sin\ \omega t$ where k is less than I.

The resultant instantaneous modulator current is now

$$I_M + kI_0\ \sin\ \omega t$$

and since the current through the choke is practically constant (but note the later remarks*) the current to the power oscillator is

$$I_0 - kI_0 \sin\ \omega t = I_0\ (1 - k \sin\ \omega t)$$

These two currents are shown in Fig. 12. Their arithmetic mean value is unchanged so that D.C. ammeters measuring I_0 and I_M should not alter in reading when modulation is occurring. Now we noted that the power oscillator behaves practically as a resistance to the comparatively low frequencies used in modulation. Therefore the voltage across it, at XY in Fig. 11, must be proportional to the current and must be

$$E\ (1 - k \sin\ \omega t)$$

This is shown in Fig. 12.

The total power supplied to the modulators is calculated by taking the average value of the product instantaneous current and the instantaneous voltage.

In Fig. 12 it will be noticed that when the current through the modulators is high the voltage is low and *vice versa*. The power supplied will therefore be less then when no modulation is taking place.

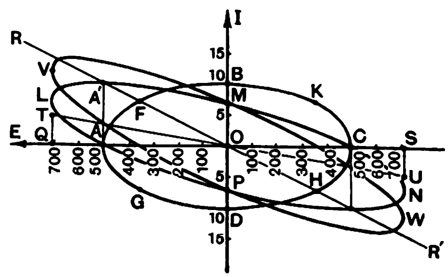


Fig. 10.

Expressing this in symbols we have :—

Power to modulators = average value of

$$E\ (1 - k \sin\ \omega t)\ (I_M + kI_0 \sin\ \omega t)$$

= average value of

$$EI_M + EkI_0 \sin\ \omega t - Ek \sin\ \omega t\ I_M - EI_0 k \sin\ \omega t$$
$$= EI_M - \tfrac{1}{2}\, k^2 EI_0$$

since the average value of $\sin\ \omega t = 0$
and the average value of $\sin^2\ \omega t = \frac{1}{2}$

* Of this voltage, E is provided from the H.T. D.C. supply whilst $kE \sin\ \omega t$ is the voltage across the speech choke, which must therefore carry an alternating current $kE \sin\ \omega t/\omega L$.

This can be made negligibly small as compared with $kI_0 \sin\ \omega t$ by making ωL large enough.

The power to the modulators is thus diminished by the amount $\frac{1}{2} k^2 E I_0$.

In the case of the power oscillator, the instantaneous values of voltage and current have their maxima at the same time. We may conclude from this that the power is increased.

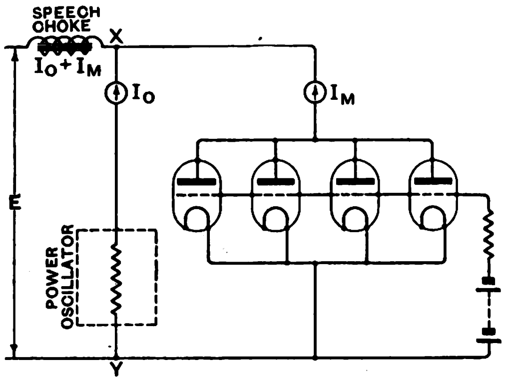


Fig. 11.

Power supplied to power oscillator
= average value of

$$E\,(1 - k \sin \omega t)\; I_0\,(1 - k \sin \omega t)$$

= average value of

$$EI_0\,(1 - 2\,k \sin \omega t - k^2 \sin^2 \omega t)$$
$$= EI_0 + \tfrac{1}{2}\,k^2 EI_0$$

The power to the oscillator is increased by $\frac{1}{2} k^2 E I_0$. The reading of the aerial ammeter should therefore increase when modulation is occurring, but under the usual conditions the change will be slight.

It is clear that k measures the depth of modulation. In the "Q" set using 4 M.T.7B valves, we saw that the maximum possible value of k was 0·64.

Therefore maximum increase in power

$$= \tfrac{1}{2}\,0.64^2\,EI_0$$
$$= 0{\cdot}204\,EI_0$$
$$= 0{\cdot}204 \times 1{,}500 = 306 \text{ watts.}$$

Maximum increase in aerial ammeter reading

$$= \sqrt{1.204} - 1 = 10 \text{ per cent.}$$

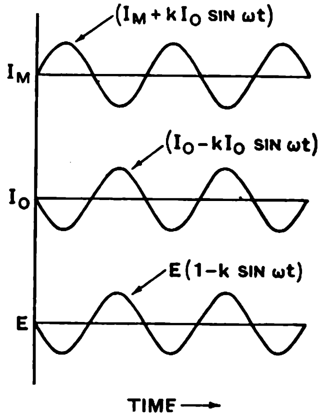


Fig. 12.

That is, with a depth of modulation of 64 per cent., the aerial current only increases 10 per cent.

For a depth of modulation of 100 per cent., the aerial current should increase

$$\sqrt{1\ 5} - 1 = 22\ 5 \text{ per cent.}$$

(The whole subject of modulation is treated very fully by Heising, in *Proc I.R.E.*, August, 1921.)

The "Law Correction" of Variable Air Condensers.

By W. H. F. Griffiths.

ONE of the most important factors to be taken into account in the design of plate shapes for variable air condensers to have definite laws connecting wavelength (or frequency) and angular movement is the minimum or "residual" capacity of the finished condenser as augmented by the capacity of the circuit of which it is to form part.

A condenser cannot therefore be designed without a knowledge of the conditions of its intended use; and from a study of the various laws it is at once seen that a slight under-estimation of the extent to which the minimum capacity will be augmented by the circuit will prevent the condenser from following closely its design law. The seriousness of a given error in the estimation of the augmented residual capacity of a condenser depends to a large extent upon the actual law to which it is to conform. It is more serious in condensers having uniform scales of frequency and not quite so serious in those having uniform wavelength scales.

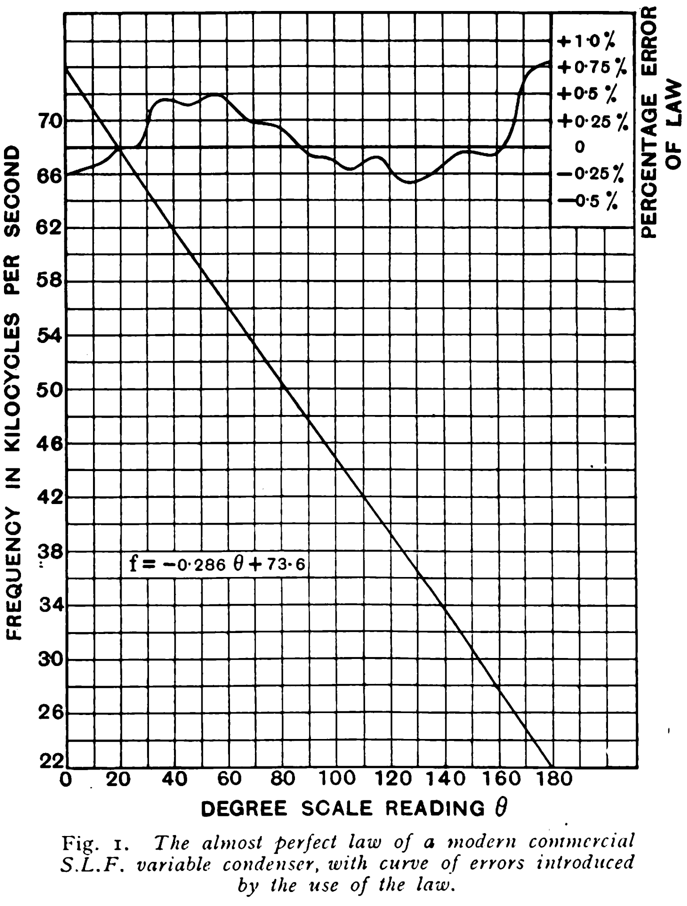


Fig. 1. *The almost perfect law of a modern commercial S.L.F. variable condenser, with curve of errors introduced by the use of the law.*

One can, of course, overestimate deliberately the value of augmented residual capacity in order to render possible a law satisfying adjustment by simply adding in parallel with the variable condenser a small fixed value unit to bring the resultant value up to that estimated. This can only be accomplished, however, at the expense of range of capacity variation; an additional $10\mu\mu F$ on the residual value of a $500\mu\mu F$ condenser may cause a 30 per cent. reduction in its capacity range.

It would be useful also when selecting a condenser for particular work to have stated the actual law of wavelength or frequency change when used with a coil of stated inductance, together with possible limits of deviation from that law.

A test recently made by the author on an S.L.F. variable condenser (commercially obtainable),* having, it is understood, a plate-shape designed by the makers, to the formulæ developed by the author,† showed how well an inexpensive "mass production" condenser can conform to its predetermined law if used in the correct manner. The

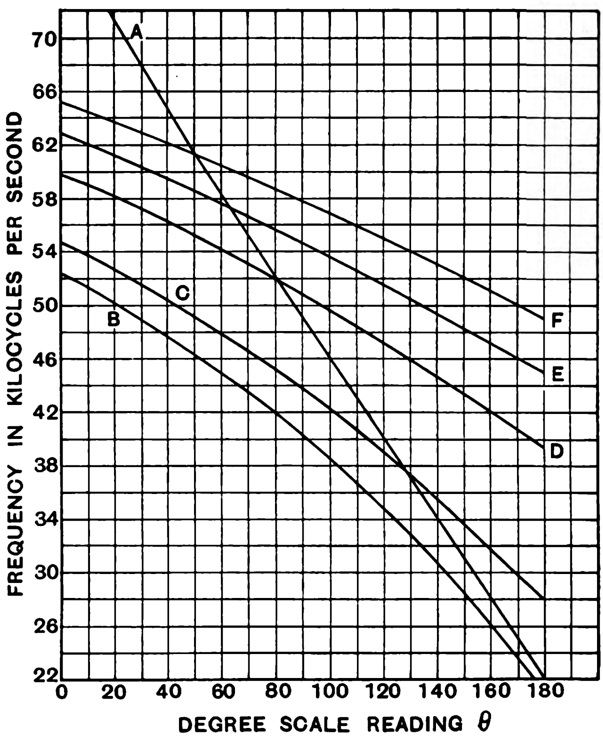


Fig. 2. *Curves illustrating the various stages of correction for the law distortion by excessive residual capacity in an S.L.F. condenser. Curve A is obtained under proper conditions. Curve B the law distortion introduced by 50μμF excess residual capacity. Curve F the finally corrected curve obtained by the introduction of a series condenser of selected value.*
(All curves in this figure are plotted from actual measurements.)

A Commercial Example of "Law Correctness."

It is seen therefore how important it is that a value of "extra" or circuit capacity should be associated with a condenser declared to have, for instance, an S.L.F. law.

*The Ormond Engineering Company's S.L.F. Condenser.

† "The Laws of Variable Air Condensers," *E.W. & W.E.*, Jan., 1926.

condenser in question had a nominal maximum capacity of 500$\mu\mu$F and in Fig. 1 is given the curve connecting its degree scale reading with the natural frequency of a simple resonant circuit formed using an inductance of $10^5\mu$H. The total augmenting capacity of the circuit was in this case 26.3$\mu\mu$F, and the actual capacity of the condenser 20$\mu\mu$F to 505$\mu\mu$F, and the law was found to be

$$f = -0.286\theta + 73.6$$

[f in kilocycles; θ in degrees.]

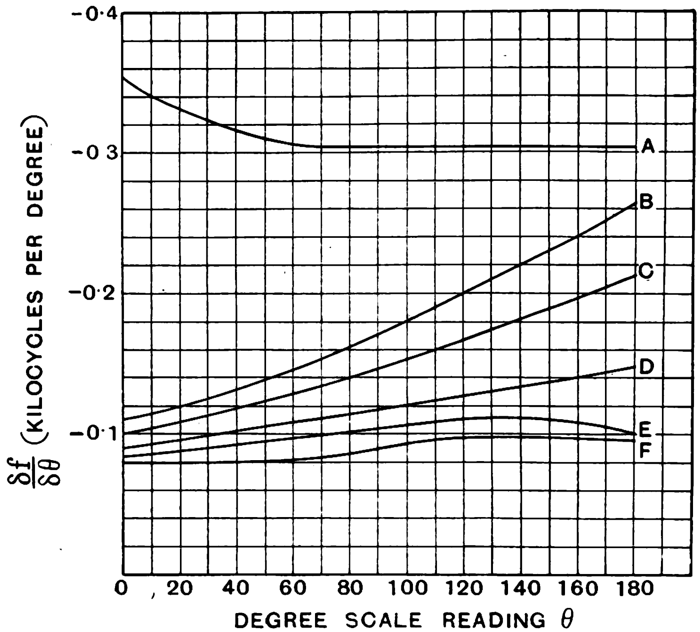


Fig. 3. *"Slope" curves to show more clearly the imperfections of the frequency curves of Fig. 2.*

S.L.F. Law.

$$f = -0.286\theta + 73.6$$

θ (degrees)	f (calculated from law)	f (exact)	Error introduced by the use of the law	θ (degrees)	f (calculated from law)	f (exact)	Error introduced by the use of the law
			%				%
2.6	72.83	73	—0.23	96.4	45.96	46	—0.09
6.0	71.86	72	—0.20	103.6	43.92	44	—0.18
12.8	69.91	70	—0.13	110.7	41.94	42	—0.14
19.5	67.99	68	—0.01	117.5	39.96	40	—0.10
25.8	65.90	66	—0.01	124.8	37.88	38	—0.32
32.5	64.25	64	+0.40	131.7	35.88	36	—0.33
39.5	62.28	62	+0.45	138.7	33.93	34	—0.20
46.5	60.25	60	+0.41	145.5	31.98	32	—0.06
53.5	58.28	58	+0.48	152.3	29.98	30	—0.06
60.5	56.26	56	+0.46	159.0	27.98	28	—0.07
67.8	54.13	54	+0.24	165.8	26.08	26	+0.30
74.8	52.12	52	+0.23	172.4	24.18	24	+0.75
81.8	50.08	50	+0.16	179.5	22.18	22	+0.80
89.3	47.98	48	—0.04				

The imperfections in the curve of Fig. 1 are so small that they are only with difficulty seen in a small scale curve, but the actual deviations from the general law are also

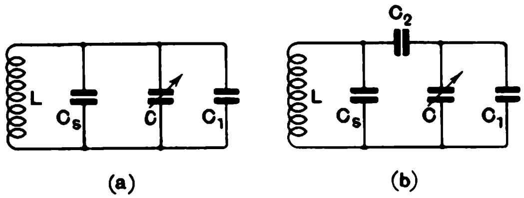


Fig. 4. *The connections of the "artificial excess residual capacity" C_1 and the series "law correcting" capacity C_2.*

deviation for 27 points, taken at intervals of exactly 2.0 kilocycles, being 0.25 per cent. as shown in the tabulation of calculated values below. The calibration points were obtained by using the even harmonics of a multi-vibrator system, vibrating at 1.0 kilocycle per second and controlled by a standard tuning fork standardised at this frequency.

Law Distortion and a Method of Correction.

The frequency curve *A* of Fig. 2 was also obtained with a coil of $10^5\mu$H, but having a somewhat smaller distributed capacity (plus leads, etc.) of $21.3\mu\mu$F. This curve, although very good, has a slight increase of "slope"

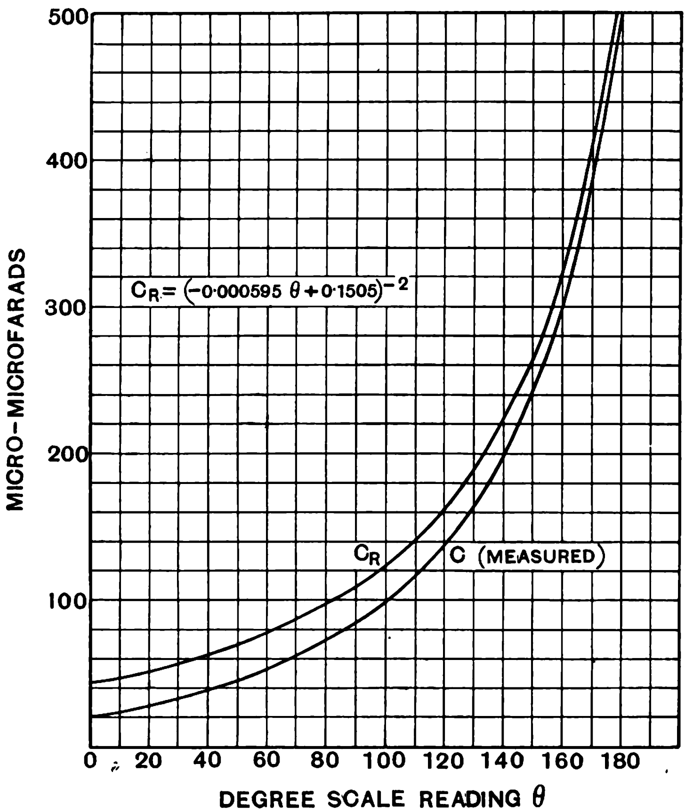


Fig. 5. *Capacity calibration curve C of a commercial S.L.F. condenser together with its corresponding "circuit value" curve C_R which follows the correct inverse square law.*

given in the curve of errors at the top of the same figure. It will be observed that the maximum deviation was 0.5 per cent. with the exception of a 0.8 per cent. departure from 170 degrees to 180 degrees. The mean

at its lower scale reading characteristic of an insufficient residual capacity augmentation; the imperfection is better shown by the "slope" curve *A* of Fig. 3. In order to show the effect on the law of too high a

value of minimum capacity, a known fixed capacity C_1 of considerable value—$50\mu\mu F$—was paralleled with the variable unit as shown in Fig. 4a.

The frequency curve B, Fig. 2, obtained under these conditions bears no resemblance to the original law, its corresponding "slope" curve being given in Fig. 3—the scale of frequency obtained was very closed up at the end. From a study of the author's article* on the design of variable condensers to straighten out again the frequency curves BB of Figs. 2 and 3.

It *is* possible to straighten these curves considerably, somewhat at the expense of total range, as is shown by the curves C, D, E and F of Figs. 2 and 3, obtained with values of C_2, 700, 190, 123, and $95\mu\mu F$ respectively.

It will be seen that curve F closely approaches the ideal uniform frequency change condition once again, although its average

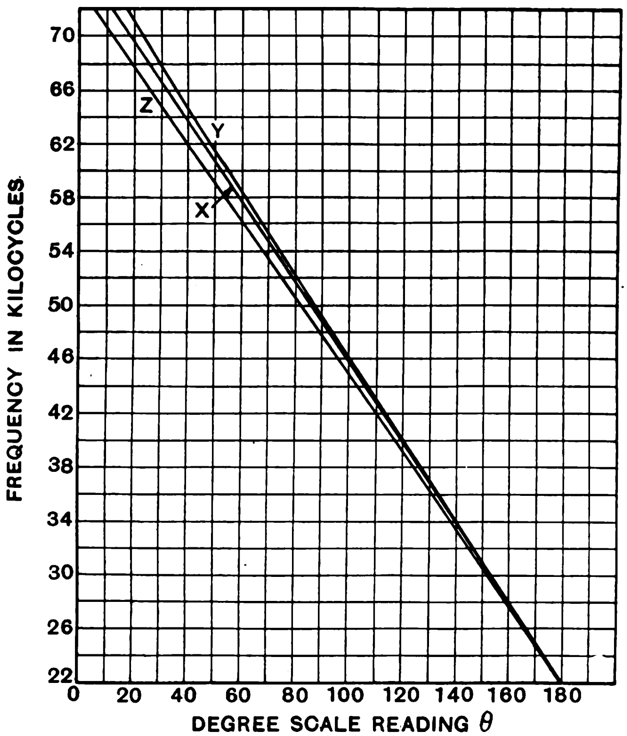


Fig. 6. *Frequency curves of an S.L.F. condenser plotted, from results of measurements and calculation, to show the effect of varying slightly the augmenting circuit capacity.*

$X = 24.0\mu\mu F$ *augmenting capacity* (*calculated*).
$Y = 21.3\mu\mu F$,, ,, (*measured*).
$Z = 26.3\mu\mu F$,, ,, ,,

to have definite laws of capacity change when connected in series with fixed value condensers, the idea will occur to connect a fixed condenser, C_2, in series with the variable condenser, as shown in Fig. 4b, in an attempt

"slope" has been reduced from about 0.18 kilocycle per degree to about 0.09. It would have been possible to have straightened out the frequency curve with a much higher value of series capacity and therefore with a much smaller reduction of "slope" had the added "excess residual capacity" been given a less exaggerated value.

* "Further Notes on the Laws of Variable Air Condensers," *E.W. & W.E.*, December, 1926.

The curve C of Fig. 5 shows the actual measured capacity of the variable condenser, and if $24\mu\mu$F be added as an allowance for circuit capacity augmentation, the curve C_R is obtained. This latter curve was found to follow the law

$$C_R = (-a\theta + b)^{-2}$$

very closely when the constants a and b were given the values 0.000595 and 0.1505 respectively, and, since this was so, it follows that the frequency change produced by it in *same condenser* would then have taken the more usual form—

$$C_R = (0.000595\theta + 0.0435)^{-2}$$

This scale reversal is, of course, not a serious fault, and would not be worth mentioning were it not for the fact that some explanation is required for the minus sign occurring in the law. The makers have, in fact, employed deliberately a reverse scale so as not to change the relative scalar positions at which well-known transmissions

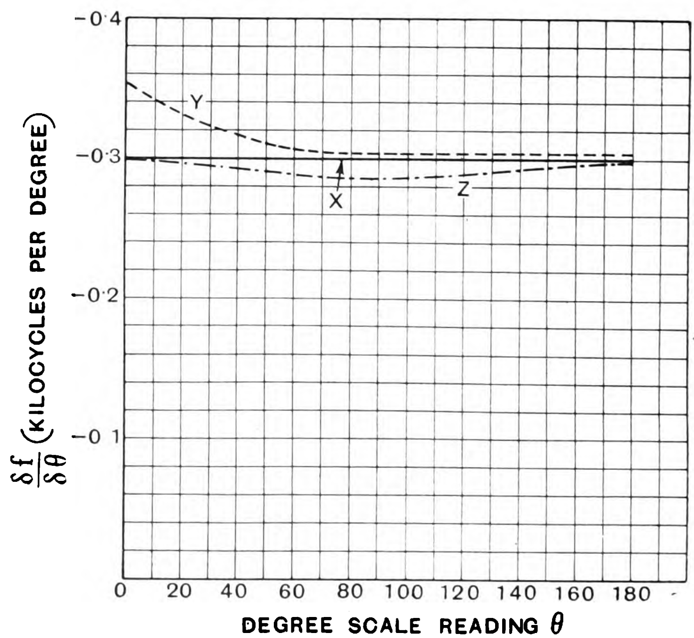


Fig. 7. "*Slope*" *curves to show more clearly the imperfections of the correspondingly lettered frequency curves of Fig.* 6.

a circuit whose augmenting capacity is $24\mu\mu$F must closely follow a linear law.

In passing, it is perhaps worthy of note that on the particular condenser under examination the scale fitted gave a decrease of frequency for an increase of degree scale reading thus necessitating the minus sign in the law

$$C_R = (-0.000595\theta + 0.1505)^{-2}$$

A scale reading in the reverse direction should more properly have been fitted so that an increase of frequency would have corresponded with an increase of degree scale reading—the corresponding law *for the* are received on ordinary S.L.C. and S.L.W. condensers.

Less "Law Distortion"—better Correction.

By employing a condenser having this law of capacity change in circuit with an inductance of $10^5\mu$H (and a circuit capacity of $24\mu\mu$F in order to reproduce exactly this capacity law) the law of uniform frequency change

$$f = -0.3\theta + 75.8$$
[f in kilocycles]

is obtained. The frequency scale of this condenser calculated from the above law is

plotted in Fig. 6 (curve X), its slope, of course, remaining constant as indicated by the horizontal line of Fig. 7. The actual measured frequencies obtained with this condenser in circuits having augmenting capacities slightly less than and greater than that for which the calculations were made are also given by curves Y and Z, the augmenting capacities (excluding the actual condenser minima) being 21.3$\mu\mu$F and 26.3$\mu\mu$F respectively.

The curves BB of Figs. 8 and 9 show the frequency law departures introduced by the of frequency when 500$\mu\mu$F and 200$\mu\mu$F respectively were the values given to this series capacity.

Curves DD show how closely a series fixed condenser can be made to compensate for incorrect circuit conditions with very little loss of range, the reduction of mean " slope " in the case under consideration being only from 0.23 to 0.15 kilocycle per second per degree.

The curve of Fig. 10 has been plotted to show at a glance the rough values of series

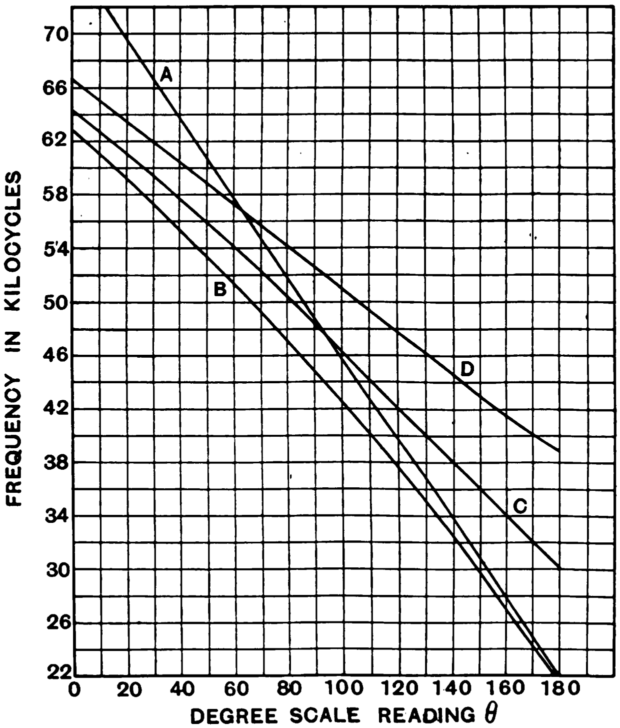


Fig. 8. *More perfect S.L.F. law correction. The excess augmentation of residual capacity is in this case much less than that for which the curves of Fig. 2 were plotted.*

addition of an *excess* of augmenting capacity of 20$\mu\mu$F only, the ideal curves AA being given in the same figures. It should be a comparatively simple matter to straighten out these imperfect curves by the introduction of a series condenser C_2 (as already indicated in Fig. 4b) without such a great loss of range or " slope " as was experienced in the previous example. The curves CC and DD were plotted from computed values capacity required to straighten out frequency curves which have been distorted by various values of circuit augmenting capacity in excess of that for which this particular condenser was designed.

The Correction of S.L.W. Condensers.

It has already been stated that an excessive residual augmenting capacity does not produce such marked departures from the

general law in the case of condensers designed to have uniform *wavelength* scales. Moreover, it is not so difficult to compensate for any law departures that do occur.

As an example of this type of condenser one having augmented or "circuit values" of 36 to 500$\mu\mu$F and following the law

$$C = (0.0909\theta + 6)^2$$

will be taken. The wavelength curve calculated from

$$\lambda = 50\sqrt{C}$$

is shown in Fig. 11.

series condenser, but the correction is not such a drastic step as in the case of an S.L.F. condenser. Fixed series condensers of the same order of capacity as that of the variable condenser produce much over-correction as shown by the curves *BB* (Figs. 12 and 13) plotted for the case of a 500$\mu\mu$F series correction condenser.

A series capacity of 2,000$\mu\mu$F is still sufficiently small to over-correct very much, as shown by the curves *CC* of Figs. 12 and 13.

By giving the series capacity the value 5,000$\mu\mu$F the correction is almost perfect,

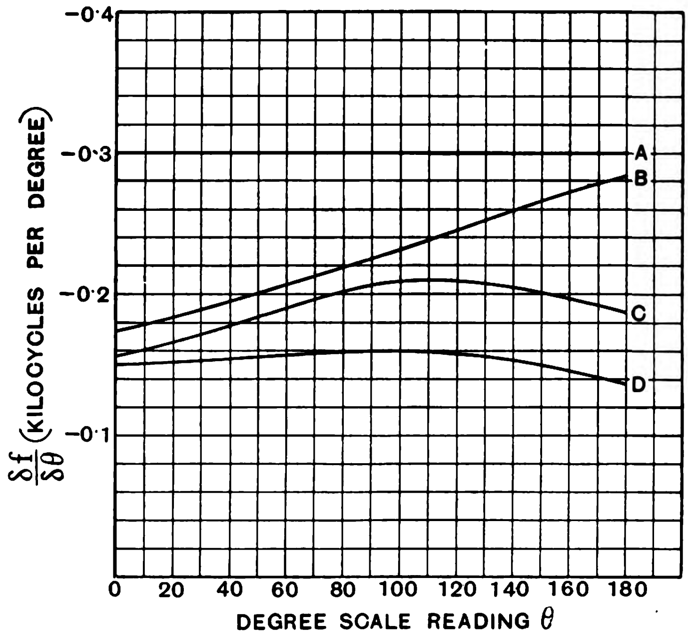


Fig. 9. *The "slope" curves to correspond with Fig.* 8.

The distortion of this wavelength curve by the addition of 20$\mu\mu$F extra capacity (in excess of that for which the condenser was designed) is shown in Fig. 12, curve *A*. The imperfections of this curve are more clearly seen from the similarly lettered "slope" curve of Fig. 13.

From these curves it will be seen that the amount of scale distortion introduced by a slight excess of circuit capacity is small in comparison with that obtained in the case of a uniform *frequency* scale condenser.

In this (present) case also it is possible to correct for the distortion by means of a

as is shown by the curves *DD*, and it will be observed that this law correction has been obtained with very little attendant loss of "range," the reduction of mean slope being only about 6 per cent. It is very interesting to note that a series capacity of the order which has given such good law correction in this case was seen to be quite useless for this purpose in the S.L.F. condenser of approximately the same capacity value and having the same value of excess residual augmenting capacity. This is, of course, due to the much greater change of $dC/d\theta$ in the case of an S.L.F. condenser, and, in

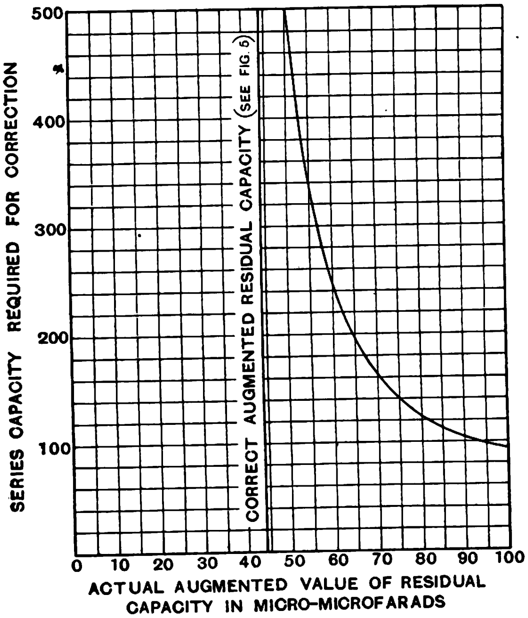


Fig. 10. *Curve showing the value of series capacity required for law correction for various values of excess augmentation of residual capacity of an S.L.F. condenser of 500μμF maximum capacity.*

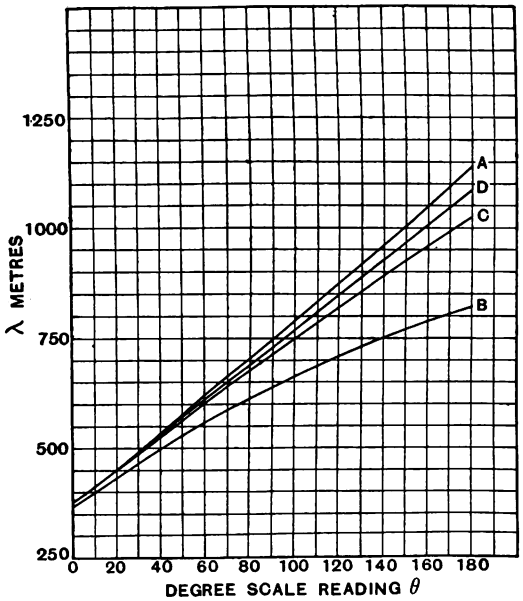


Fig. 12. *The correction (and over-correction) of the imperfect wavelength curve A.*

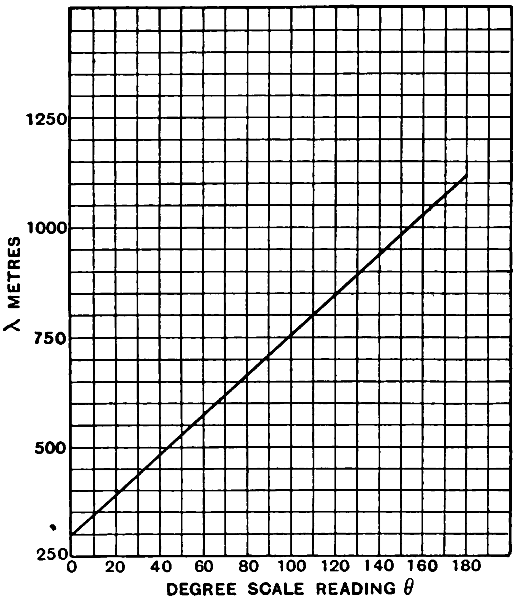


Fig. 11. *A perfect law for a " corrected square law " or S.L.W. condenser. (See Fig. 12 for imperfections introduced by excessive capacity augmentation and for law corrections by a series capacity.)*

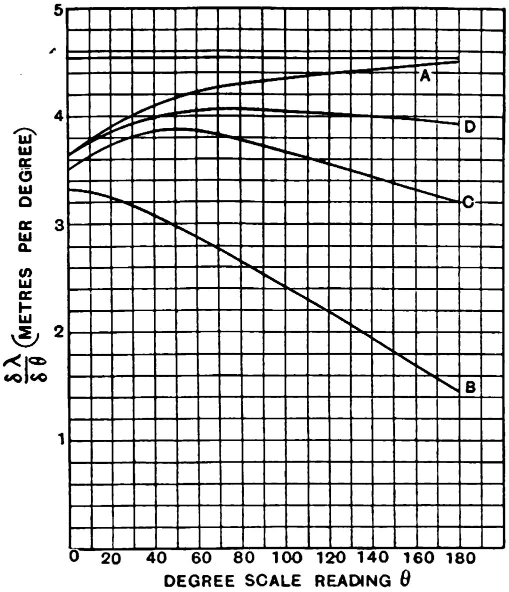


Fig. 13. *" Slope " curves lettered to correspond with the wavelength curves of Fig. 12.*

general, the greater the ratio of $dC/d\theta$ at 180 degrees and 0 degrees of the condenser scale (or the greater the ratio of moving plate radii at 180 degrees and 0 degrees) the greater will be the law alteration for a given excess of residual augmenting capacity and the more difficult will be the correction for law departures.

Conclusion.

In conclusion, it should be stated that although it is possible to design condensers which conform very closely to special laws of wavelength and frequency change, and, if necessary, to correct for varying circuit capacities, etc., it is better to employ variable condensers having uniform capacity scales where exact conformity to law is absolutely essential.

Tuning condensers in radio receivers need only conform approximately to law, but the variable condensers of wavemeters and measuring apparatus generally must conform *exactly* to law in order that the errors introduced by interpolation between points for which a calibration has been obtained may be reduced to a minimum.

The law of a semi-circular plate variable condenser remains purely linear whatever the circuit capacity happens to be and no adjustment is therefore necessary after the original law perfecting adjustments (mechanical in nature) have been effected.

It is often necessary to reduce the total capacity range of a variable condenser in measuring apparatus to quite a small percentage of the total capacity in use, by setting up its zero by varying amounts, by means of parallel condensers of fixed values. This can be done without fear of the introduction of interpolation errors since a full knowledge of the law is always possible if a uniform scale of capacity has once been obtained.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page 419 of July issue.*)

PART III.

THE DIFFERENTIAL AND INTEGRAL CALCULUS.

1. The Object and Scope of the Differential Calculus.

THE Differential Calculus is concerned with the systematic study of variation, and its field of application is therefore co-extensive with the whole domain of natural phenomena. As Professor Whitehead has expressed it, ". . . the fundamental idea of change, which is at the basis of our whole perception of phenomena, immediately suggests the inquiry as to rate of change. . . . Thus the differential calculus is concerned with the very key of the position from which mathematics can be successfully applied to the course of nature."

2. Rate of Change.

The first requirement is make quite clear what is meant by "rate of change." Rate is the same word as ratio, so that "rate of change" can be paraphrased as "ratio of changes," in which form its meaning is already much clearer. It implies two quantities, one of which changes in consequence of a change in the other. In more technical language, it implies a function and an independent variable. The rate of change of the function is thus the ratio of the change in the function to the change in the variable which produces it.

The most suitable example to take will be that one the contemplation of which first evoked in the brain of Newton the ideas on which the present form of the calculus is based—a body moving in space, or, to make it a little less abstract, a train moving along rails. The distance (measured along the rails from some fixed point) which is travelled by the moving train is, in the full mathematical sense of the word, a function of time. In all such physical problems, "time" means, of course, an interval of time measured from some arbitrary "zero" of time. (Anyone who served in the war will know only too well what "zero hour" means.) To fix ideas in the above instance, we will take as the origin of distance some fixed point on the rails and as the origin or "zero" of time the actual clock time at which the engine passes this fixed point. The distance from the fixed point will be represented by the symbol s, which stands for a number (of miles, feet, inches, or whatever unit is most convenient) and the time will be represented by the symbol t (also a number of hours, minutes, seconds, or whatever time unit is most convenient). Then in general

$$s=f(t)$$

Suppose we are told that in a given case the form of the function is linear (see Section 5, Part I, October, 1926), *i.e.*,

$$s=a+bt$$

a and b being constant numbers. In the interval of time between t and $t+\delta t$ (δt being considered as a single symbol meaning "a change of t") s will increase by an amount which we will represent by δs. The relation between $s+\delta s$ and $t+\delta t$ is that given above, *i.e.*,

$$s+\delta s=a+b(t+\delta t)$$
$$=a+bt+b\delta t$$

and since $$s=a+bt$$
$$\delta s=b\delta t$$

Therefore the ratio of the change of s to the change of t is

$$\delta s/\delta t=b$$

b representing a certain number of miles per hour or feet per second or whatever the selected units may be. It is in fact the speed or velocity of the train, and since it does not depend either on t or on δt the movement of the train is completely described by the single constant b.

But now suppose that the form of the function is given as

$$s=a+bt+ct^2$$

Then in precisely the same way as before it will be found that

$$\delta s=b\delta t+2ct\,\delta t+c\,\delta t^2=(b+2ct+c\delta t)\delta t$$

so that the rate of change of s is

$$\delta s/\delta t=b+2ct+c\delta t$$

This depends not only on t, the beginning of the interval δt, but also on δt, the length of the interval. If the interval δt could be reduced to zero we could say that at the instant t the train was travelling at a speed $(b+2ct)$ miles per hour or whatever the units might be. But that is just what we cannot do. One cannot measure the distance travelled in zero time. Putting it mathematically, since

$$\delta s=(b+2ct+c\delta t)\ \delta t$$

we get by dividing each side by the quantity δt the ratio

$$\delta s/\delta t=(b+2c\delta t+c\delta t)\ (\delta t/\delta t)$$

and if we reduce δt to zero the second term on the right-hand side becomes (0/0) which is not a number at all and may mean anything or nothing. (See para. E.4, August, 1926.)

This is the difficulty which confronted Newton. He probably solved it for himself so completely that he lost sight of the difficult character of the ideas involved. Be that as it may, he did not resolve the difficulty in language sufficiently clear to prevent confusion of thought on the part of some of his disciples. The more discerning mathematicians were greatly worried by this difficulty for a long while after Newton. It did not worry the less discerning ones, for they blotted it out under a cloud of bad philosophy—the sepia principle, invented by the octopus. It appeared that the quantity δt had to be both zero and not zero. "Fancy that!" they said, "What a wonderful quantity it must be!" and gave it a wonderful name, calling it an "infinitesimal." But, unfortunately, as Napoleon remarked on one occasion, "You can call a thing what you like but you cannot prevent it from being what it is." The infinitesimal in its original form was a disappointing child, and died comparatively young.

Actually, of course, there is no need for any mysticism in this matter. The difficulty is completely resolved by means of the conception of "limit" described briefly in Section 8 of Part I (February, 1927). The reader is strongly advised to read this section again, or, better still, to re-write it for himself in his own words. That is always the best way of learning a new set of ideas.

As long as δt remains finite, however small it may be, then $\delta t/\delta t$ is 1, and

$$\delta s/\delta t=(b+2ct)+c\delta t$$

Now by taking δt sufficiently small $\delta s/\delta t$ can be made to differ from $(b+2ct)$ by less than any assigned amount, *i.e.*, it can be made to approximate to $(b+2ct)$ within every standard. This is expressed symbolically

$$\underset{\delta t\to 0}{lt.}\ (\delta s/\delta t)=b+2ct.$$

The expression on the left is inconveniently long to write down and it is commonly abbreviated to ds/dt. Thus, if

$$s=a+bt+ct^2$$
$$ds/dt=b+2ct$$

The symbol ds/dt is called "the differential coefficient of s with respect to t." Notice "the symbol ds/dt"—not the fraction ds/dt, because it is *not* a fraction. The parts ds and dt considered separately are quite undefined. The ds is *not* the limit of ds when ds tends to zero, because then ds would be zero. Similarly for dt. The symbol ds/dt is always to be considered as single and undecomposable like any other simple algebraic symbol—x for instance. It is no more than a convenient abbreviation for

$$\underset{\delta t\to 0}{lt.}\ \delta s/\delta t.$$

There are various other ways of writing the differential coefficient which will perhaps be met with later, but this one is universally accepted and will be used exclusively for the present.

In the present instance the number ds/dt is the instantaneous velocity of the train at the instant t. It is called instantaneous because there is no finite interval of time for which it remains constant. At a particular instant t_1 its magnitude would be $(b+2ct_1)$. The magnitude of ds/dt at the instant t_1 can conveniently be written ds/dt_1, or alternatively $(ds/dt)_{t=t_1}$. The first is preferable for compactness, but the second is more explicit.

The differentiation of s with respect to t leads to the equation

$$ds/dt = b + 2ct.$$

This is known as a differential equation, this name being applied to any equation in which differential coefficients appear. By the solving of a differential equation is meant the reversing of the process that has just been described, *i.e.*, deriving from the differential equation the ordinary algebraic equation to which it corresponds. Notice that in the present case for given values of b and c the differential coefficient would be the same whatever the magnitude of a in the original equation. There are therefore an infinite number of solutions of the above differential equation, and additional information (generally referred to as a "boundary condition") is required to make the solution complete and unique for the given case considered. Suppose for instance we are told that

$$dy/dx = px + q$$

p and q being known numbers, and that y is known to have the value y_0 when x is zero. By analogy with the equation that has just been considered the solution of the above differential equation is

$$y = (p/2)x^2 + qx + K$$

where K is any independent constant number. But we are told that the relation between y and x is such that when x is zero y is y_0. Putting these related values in the above equation

$$y_0 = (p/2)0 + q0 + K = K$$

so that the complete solution for y is

$$y = (p/2)x^2 + xq + y_0$$

being the only expression for y which satisfies both the differential equation and the given "boundary condition."

This, however, is by way of a digression. It is put in simply to show what is meant by a differential equation and by the solution of a differential equation, and is included at this place because it follows so naturally from the above introduction to the differential coefficient. It is with the latter that we are more concerned at the moment and the next thing to do will be to generalise this important idea.

3. General Definition of "Differential Coefficient."

Given that y is a function of x, the differential coefficient of y with respect to x at any value of x in the neighbourhood of which the function is finite and continuous is defined by

$$\frac{dy}{dx} \text{ or } \frac{d}{dx}f(x) = \underset{h \to 0}{lt.} \frac{f(x+h) - f(x)}{h}$$

The reader should have no difficulty in seeing that this is only the general statement of the process which was illustrated for a particular function in the preceding section.

4. Geometrical Interpretation of the Differential Coefficient.

The curve shown in Fig. 29 is assumed to represent the variation of $f(x)$ with x, *i.e.*, if $OS = x$, $SP = f(x)$. An increase of x from

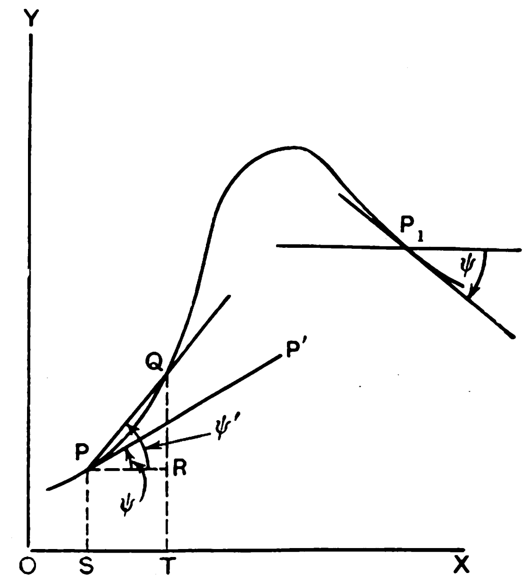


Fig. 29.

OS to OT produces in $f(x)$ an increase represented by RQ. Therefore putting h for the magnitude of PR,

$$\frac{f(x+h) - f(x)}{h} = \frac{RQ}{PR} = tan\ \psi'$$

As h tends to zero, Q moves down the curve towards P. In the limiting position when Q tends to coincidence with P the chord PQ becomes what is known as the tangent at P.

Therefore if PP' in Fig. 29 represents the tangent at P to the curve which represents the function, then

$$\frac{d\,f(x)}{dx} = \underset{h\to 0}{lt.}\ \frac{f(x+h)-f(x)}{h} = \tan\psi$$

where ψ is the inclination of the tangent at P with respect to the x axis. For this reason the differential coefficient is sometimes referred to as the slope of the function.

5. The Sign of the Differential Coefficient.

If at the point $x, f(x)$ is increasing with x (as at the point P in Fig. 29) then

$$f(x+h)-f(x)$$

will be a positive number and the differential coefficient will be positive. Conversely if the function is decreasing with x, as at the point P_1 in Fig. 29, then the differential coefficient will be negative in sign, corresponding to the fact that the tangent makes a negative angle with the x axis.

6. The Differentiation of Positive Integral Powers of x.

The differentiation of $y=x^n$ where n is a positive integer is a good illustration of the application of the above general definition of the differential coefficient. By the Binomial Theorem,

$$(x+h)^n = x^n + nx^{n-1}h + \frac{n(n-1)}{2}x^{n-2}h^2 + \frac{n(n-1)(n-2)}{2.3}x^{n-3}h^3 \text{ etc.}$$

there being $n+1$ terms in the expansion. Therefore as long as h is finite

$$\frac{(x+h)^n - x^n}{h} = nx^{n-1} + \frac{n(n-1)}{2}x^{n-2}h$$

+ terms containing h^2 and higher powers of h.

By taking h sufficiently small, the right-hand side can be made to differ from nx^{n-1} by less than any finite quantity, however small. Therefore

$$dy/dx = dx^n/dx = \underset{h\to 0}{lt.}\ \frac{(x+h)^n - x^n}{h} = nx^{n-1}$$

For instance $dx^2/dx = 2x$; $dx/dx = 1$. Notice that the above determination of dx^n/dx depends on the fact that the limit of the sum of a *finite* number of terms is the sum of the limits of the terms. The reader is cautioned against assuming that the limit of the sum of an *infinite* number of terms is equal to the sum of the limits of the terms. It may or may not be so, and frequently isn't.

If the above brief introduction to the differential calculus is thoroughly understood, the reader will have no difficulty in understanding the subsequent sections of this part of the series, which will consist mainly of applications and developments of these few comparatively simple ideas.

Examples.

1. Show that the area of a parallelogram having the vectors **a** and **b** as sides is $\sqrt{(ab)^2-(\mathbf{a}\cdot\mathbf{b})^2}$.

2. Two sides of a triangle are 10 cms. and 25 cms. in length, and the angle between them is 50°. Find the length of the third side.

3. Given that *sin* 60° is .866, calculate *tan* 60° and *sec* 60°.

4. Show that :—
   (i.) $\tan(A+B) = (\tan A + \tan B)/(1-\tan A \tan B)$.
   (ii.) $\tan 2\theta = 2\tan\theta/(1-\tan^2\theta)$.
   (iii.) $\sin 3\theta = 3\sin\theta - 4\sin^3\theta$.
   (iv.) $\cos 3\theta = 4\cos^3\theta - 3\cos\theta$.

5. Given that :— $z_1 = 3+j4$
   $z_2 = 4+j5$
   $z_3 = 5+j6$
   (i.) Find $|z_1|$, $|z_2|$, $|z_3|$.
   Express in the form $r\varepsilon^{j\theta}$
   (ii.) $(z_1+z_2+z_3)$.
   (iii.) $(z_1+z_2-z_3)$.
   (iv.) $(z_1+z_2)/z_3$.
   (v.) $(1/z_1)+(1/z_2)+(1/z_3)$

6. Show that the vectors $\{(a-b)+j(d-e)\}v$, $\{(b-c)+j(e-f)\}v$, $\{(c-a)+j(f-d)\}v$ form a triangle.

7. Express in the form $(a+jb)$ the cube roots of $(1+j2)$.

8. The instantaneous rate of motion of a particle moving in a straight line is given as $50+100t$ cms. per second. How far will it travel in an hour from its position at the instant $t=0$?

9. The distance from a fixed point travelled by a particle moving in a straight line is given as $10+500t-5t^2$ cms., t being the time in seconds. At what distance from the starting point will it come to rest, and in how long ? How long will it take to return to its starting point ?

(To be continued.)

The Hot-Wire Microphone and Audio-Resonant Selection.

Paper read by G. G. BLAKE, M.I.E.E., F.Inst.P., to the Radio Society of Great Britain at the Institution of Electrical Engineers, 25th May, 1927.

IN a lecture before the Royal Society in 1880, Sir William Preece described a thermo-telephone receiver, which consisted of a tightly stretched length of fine platinum wire, fixed at one end and attached at its other extremity to the centre of a diaphragm, as shown in Fig. 1(*a*).*

The wire is heated by a current from battery *B*, and the expansion and contraction of the wire in response to words spoken towards the microphone *M*, cause the diaphragm to vibrate.

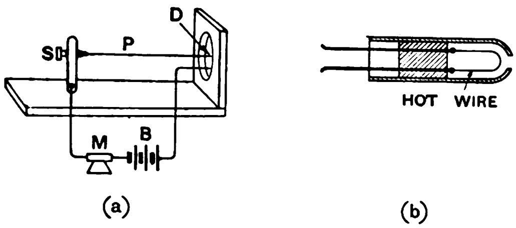


Fig. 1.

In 1887 Prof. Geo. Forbes, in a paper before the Royal Society, described the employment of a red hot wire as a telephone transmitter. A fine platinum wire was included in circuit with a battery and the primary of a transformer, the secondary of which was connected to a telephone receiver. When the wire was incandescent, words spoken towards it could be heard in a receiver owing to its change of resistance, due to the cooling action of the air movements (sound waves). This form of transmitter was insensitive to mechanical vibration.

In 1906 Dr. Eccles† invented a telephone receiver which he called a "Thermophone." This is shown in Fig. 1(*b*). The instrument was actually inserted in the ear of the listener, and the expansion and contraction of the air within the tube and the aural passages, due to the rapid changes of temperature of a fine platinum wire, affected the human diaphragm, and could be heard without any other mechanism.

Hot wires have of course been employed for many purposes in connection with radio, for example Fessenden's barretter (patented in 1902),* Duddell's thermo-galvanometer, hot wire milliameters of various types, Langley's bolometer, Tissot's bolometer bridge,† The Snow Harris thermo-galvanometer,‡ etc.§

In 1923, in a lecture before the Royal Society of Arts, Major W. S. Tucker‖ demonstrated the extraordinary sensitiveness of a hot wire to sounds, when it was included in one arm of a Wheatstone bridge, and placed at the orifice of a suitably constructed acoustic resonator. By tuning the latter the hot wire was only affected by the note to which it was tuned. He described how this instrument was successfully employed during the Great War in locating the enemy's big guns, and how it detected them without experiencing interference from nearby rifle fire and other noises, which so far as ordinary oral reception was concerned, entirely obliterated the sounds of the distant big guns.

The din of battle could be rejected with

* Fig. 1 is a reproduction from G. G. Blake's *History of Radio-Telegraphy and Telephony*. Reproduced by the courtesy of the Radio Press (the Publishers).

† See *Handbook of Formulæ, Data and Information*. By W. H. Eccles. Published by the Electrician Printing and Publishing Co.

* See G. G. Blake's *History of Radio-Telegraphy and Telephony*.

† See *Journal of I.E.E.*, 1906.

‡ See *Handbook of Wireless Telegraphy*. By J. Erskine-Murray.

§ Our Chairman (of the R.S.G.B.), General Capel Holden, has himself made a number of inventions which embody the employment of a hot-wire. See "Holden–d'Arsonval Universal Reflecting Galvanometer." *Electrician*, vol. 29, p. 589, 7th July, 1893. Both the Holden hot-wire recording voltmeter and ammeter are manufactured by Messrs. James Pitkin.

‖ See also *Phil. Trans.*, 1921, 221, A.389.

ease, as it consisted of sounds having far shorter wavelength than those coming from the distant guns, to which the resonator was tuned. This demonstration which I witnessed impressed me with the idea that the hot wire microphone and resonator might be employed for audio-resonant radio reception. In a paper to the Radio Society of Great Britain in 1924* the writer

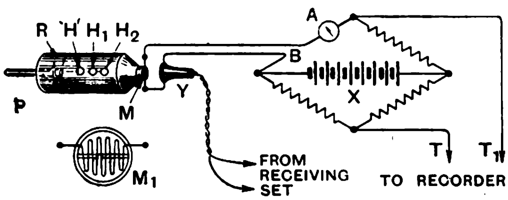


Fig. 2.

suggested that when two or more stations are jamming one another to such an extent that it becomes a difficult problem to cut out the interfering stations, use might well be made of the hot wire microphone and acoustic resonator.

Fig. 2† illustrates the scheme in which the signals should be given a distinct note at the transmitting station, either by a spark interrupter operating at an audio-frequency, or in the case of C.W. transmission by tonic train interruption; or alternatively that the required musical note could be produced by heterodyning at the receiving station.

In the American journal *Radio News* for December, 1926, a description was given by O. C. Roos of the "Acoustat." In this instrument resonating tubes are employed in quite another manner, for the elimination of statics. This apparatus has been employed at Rockland, Maine. Its action is briefly as follows: Signals are first received in the usual manner by aid of a heterodyned receiver, and given a pure note of known acoustic frequency. The telephone receiver is then placed in front of a "Percussion" chamber, which turns the noise of the static cracks into one pure musical tone, carefully arranged so as not to resonate with the note previously given to the incoming signals; by the employment of a suitable series of resonating chambers it is possible to pass both these sounds, and by placing a receiver in the right position to pick up the signals and to reject the unwanted note produced in the "Percussion" chamber by the atmospherics. The signals are brought to focus by a concave sound reflector at the diaphragm of a telephone receiver, the movements of the diaphragm of which generate currents which are amplified as may be found necessary for recording or aural reception. The system is based, I believe, upon a scheme of audio-resonant selection for spark signals developed in 1910 or 1911 by Braun in Germany.

In 1927 Dr. H. E. Watson of the Indian Institute of Science, Bangalore, published a paper describing how he had put the writer's suggestion to the test.*

Fig. 3(*a*) shows the circuit he employed :—

R is a 3-valve receiver.

A is C Mark II. audio - frequency amplifier.

T is a resonator with a hot wire microphone at its centre instead of at its end. This consisted of a Wollaston wire 0.00024 in. run at a dull red heat.

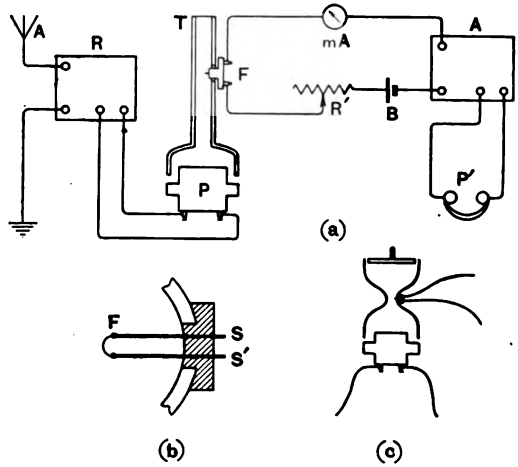


Fig. 3.

Fig. 3(*b*) shows his method of mounting the Wollaston wire by soldering it across two 40-gauge Constantan wires.

* "Some Suggested Lines for Experimental Research," *Wireless World*, Vol. XIV., 25th June, 1924.

† Reproduced by permission of the Publishers from G. G. Blake's *History of Radio-Telegraphy and Telephony*.

* Paper "The Tucker Microphone for Reception." Prof. H. E. Watson, D.Sc., *E.W. & W.E.*, Vol. IV., March, 1927, pp. 148-150.

Fig. 3(*c*) is another form of resonator which he employed.

The following is a quotation from his paper :—

" Finally a few words may be said as to the selectivity of the microphone as experimentally determined. The apparatus was not suitable for quantitative measurements by the Wheatstone bridge method and so the experiments were merely qualitative. It may be mentioned, however, that they are of the order which would be expected if the resonance curve at a frequency of 1,000 were similar to the one given by Tucker & Paris for 250 periods.

" In one experiment, Madras (VWO), working on 4,000 metres, was tuned in"— on a particularly unselective receiver— " autodyne reception being used. A local oscillator was arranged to transmit Vs on a near wavelength so that the signals received were much weaker than those from VWO. Tuning was carried out by means of a vernier condenser. When VWO was tuned in the Vs were almost inaudible; when the local oscillator was tuned in, the signals from VWO were audible but not loud enough to interfere with accurate reading. The change of the capacity of the condenser between the two settings was 6$\mu\mu$F, say 1 in 250, corresponding to a change in frequency of 1 in 500, *i.e.*, 150 cycles for the frequency of 75 kilocycles employed.

" The corresponding wavelength difference of the two transmissions is only 8 metres. As it is the difference in frequency which determines the change of pitch of the beat note, it is this quality which we will assume to be about 150 cycles, for signals not differing very widely in intensity, which determines the possibility of separating two signals whatever the operating frequency.

" Expressed in wavelengths, a separation could be effected of two stations working not less than 200 metres apart at 20,000 metres, or 0.02 metre apart at 200 metres. By using a beat note of lower frequency, still sharper separation could be obtained, but as already pointed out, other factors render this inadvisable. Data regarding the performance of tuned audio-frequency transformers appear to be scanty, reference may however be made to a paper on the subject by A. Pagès.* From the one resonance curve given, the selectivity of the transformers described appears to be considerably inferior to that of the hot wire microphone.

" The effect of the microphone upon the confused noises usually heard when receiving upon the longer wavelengths with an unselective receiver is striking. With perhaps a few exceptions each station may be tuned in separately and clearly. For example, no trace of the strong signals from SIAGON (HZA 15,750 metres) or Malabar (PKX, 15,600 metres) could be heard when listening to Lyon (YN, 15,300 metres)."

Having followed the applications of the hot wire up to this point the writer decided to conduct some experiments on his own account.

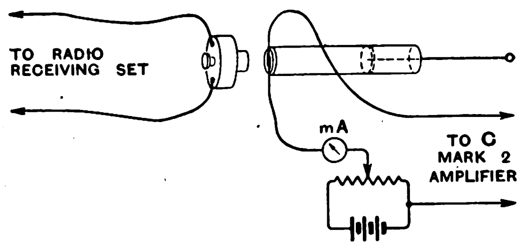


Fig. 4.

Fig. 4 illustrates the first experiment.

Signals from numerous C.W. and spark stations were received on an ordinary autodyne receiving set, consisting of one valve detector followed by one stage of note magnification, and in the case of weaker stations by two stages. Signals were received on various wavelengths.

Three resonators were tested, the smallest consisted of a tube ½ in. in diameter and 9 in. long, resonating to a wavelength of 3 ft., and having a frequency of approximately 373 when its plunger was fully extended.

The next resonator was 1 in. in diameter and 21 in. long, this when the plunger was fully extended had a wavelength of 7 ft. and an approximate frequency of 160.

Another resonator was 6 in. in diameter and 15 in. long; roughly not allowing any extra for its excessive diameter, this had an approximate wavelength of 5 ft. and a frequency of 224.

All these resonators worked well. In practice it was found that the best scheme was to set the resonator to respond to some predetermined frequency, say to a

* *L'Onde Electrique*, June, 1926, pp. 276-283.

frequency of about 376 (9 in. long) and to heterodyne the incoming signals to give a beat note of that same frequency. For these early experiments a 0.00024 Wollaston wire was employed. A heating current of 4.5mA was supplied from a 6-volt accumulator, which maintained the filament at a dull red heat, both potentiometer and series resistance control were alternately employed, with equally good results. The circuit was completed through the primary of the input transformer of a "C Mark II." amplifier,

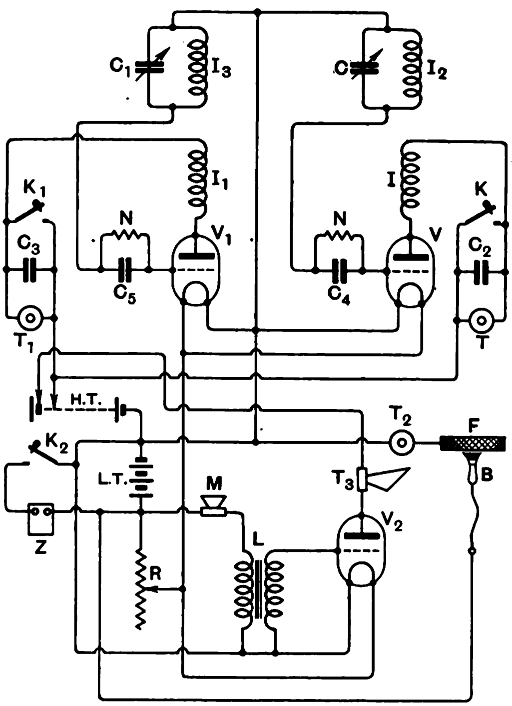


Fig. 5.

and the signals were finally received by headphone. It should be mentioned also that an adjustable slit diaphragm was employed with the resonators.

The results were most encouraging, even when several stations were working with considerable interference and when atmospherics were bad only the selected station could be heard. In order to put the selectivity of the hot wire microphone to a more stringent test, the writer next fitted up the arrangement shown in Fig. 5. The arrangement of my "Interference tester," as will be seen, comprises four separately controlled circuits. all of which obtain their H.T. and L.T. supply from a common source.

Morse keys K and K_1 control two separately tuned oscillating valve circuits. Normally the keys short circuit the telephone earpieces T and T_1, and notes are sounded in the phones when the keys are depressed. The frequency of the notes can be controlled in several ways: By an adjustable grid-leak and fixed grid condenser, or by the employment of a fixed grid-leak and an adjustable grid condenser.

Another method is to employ a fixed condenser and grid-leak, and to alter the frequency by the insertion to a greater or less extent of an adjustable iron core within the fields of the grid and plate coils.

Or again, the frequency can be controlled in the manner we are employing this evening, by means of a variable condenser across the grid coil.

There are doubtless various other methods which might be employed, for instance the adjustment of the filament current, or the plate voltage, or the coupling between the grid and plate coils, or again variometer tuning might be employed.

Key K_2 controls a simple buzzer circuit.

The fourth circuit shown on this slide was employed to produce unpleasant noises to approximate the sounds of atmospherics, these noises were produced in phone T_3, when a steel file F was brushed with a metal brush B.

For the purpose of our demonstration this evening, I have removed this arrangement and substituted a simple telephone earpiece, which is connected to a valve receiving set connected to the outside aerial. In order to save me the trouble of having to bring an excessive amount of apparatus, my friend Mr. Maurice Child has kindly brought along his receiving set, and I will now ask him to pick up some C.W. signals.

These we will mingle with our artificially produced interference, and I will then endeavour to demonstrate to you that it is possible to rescue them again from the apparently hopeless jumble of interfering sounds.

Before we put on the next slide please again note the three telephones T, T_1 and T_2 and the buzzer Z. The three phones

and buzzer, as will be seen from Fig. 6, are all mounted on a baseboard, forming the back of a concave cavity, where all the sounds are collected and directed against a paper diaphragm D to the centre of which is attached a microphone.

The microphone currents are amplified by a valve V_2 (which was also shown in Fig. 5).

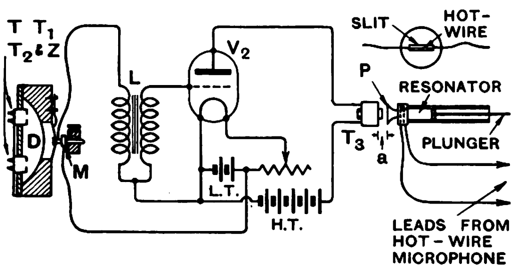


Fig. 6.

Demonstration.

You can now hear four sets of signals all interfering. Referring again to Fig. 6, you will see that the loudspeaker (denuded of its horn) is now placed in front of a resonator fitted with a hot wire microphone.

Numerous experiments were made with different wavelengths. Wollaston wire of various gauges were tested, and the best results were obtained by the employment of a single wire $\frac{3}{16}$ in. long and 0.0001 in. in diameter. In order to obtain the maximum cooling effect from the pulses of air (sound waves) as they pulsed through the mouth of the resonator, a slit diaphragm was employed (see inset Fig. 6). The width of this slit was critical and was arrived at experimentally. In order to obtain really sharp tuning, and to make the arrangement extremely selective, in addition to tuning the resonator accurately by means of its plunger, to the same frequency as the beat note of the received signals, it is necessary (in order to prevent forced resonance) to adjust the distance between the loudspeaker phone T_3 and the resonator, according to the strength of the received signals, as shown at (*a*).

During the initial experiments the hot wire microphone was heated by means of a 4-volt accumulator, the heating being controlled either by a potentiometer or a series resistance as already described. The variations in current as determined by a milliammeter in the hot wire circuit were (even for powerful signals) in the order of less than 1mA, *i.e.*, with a steady filament heating current of 16.5mA the current rose during the reception of a signal to a value of 17.4mA.

Although it would not be difficult to devise means of recording directly with these small current changes (one very simple way which occurs to me would be to make use of a device described by J. H. Powell* in 1924. In place of a recording pen he places a small speck of radium under the needle of a galvanometer movement. The rays from this fall upon photographic paper on a revolving drum—the latter need not be in the dark, as the radium rays easily penetrate through a layer of black paper which protects it from the light until it is developed. With this arrangement the needle need not touch the paper, and there is therefore no friction).

I decided to make things more certain by the addition of one stage of amplification, and for this purpose I employed the " Zero shunt " circuit.

Before proceeding further I may perhaps make a biographical note on this subject, the zero shunt as originally devised by J. J. Dowling† is shown in Fig. 7. As can

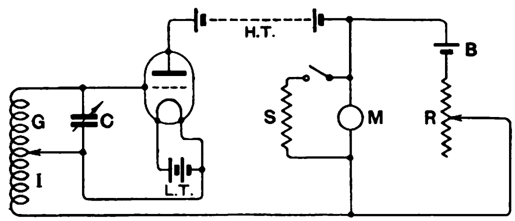


Fig. 7.

be seen the steady plate current is balanced out by an opposed E.M.F. applied from a battery B in series with a high resistance,

* J. H. Powell " Radium Recording Devices." *Journal of Scientific Instruments*, Vol. I., April, 1924, pp. 205-209.

† See G. G. Blake's *History of Radio-Telegraphy and Telephony*. Radio Press.

J. J. Dowling, *Proc. Royal Dublin Society*, Vol. XVI., 1921, pp. 175-184 and pp. 185-188; also *Phil. Mag.*, Series Six, Vol. XLVI., July, 1923, pp. 81-100.

which together form a shunt circuit across a galvanometer *M*.

In 1926 the writer* published the circuit shown in Fig. 8. in which it will be seen that the opposing E.M.F. is obtained from the filament heating battery by means of a potentiometer. As this circuit enabled a Siemen's relay to be operated quite satisfactorily in the plate circuit of a B.T.H.

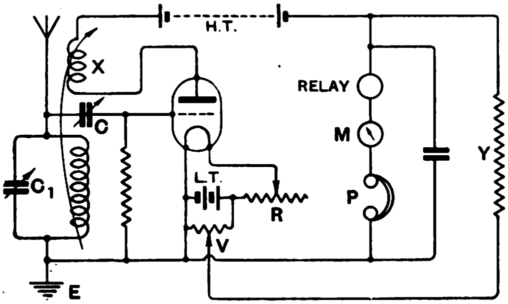


Fig. 8.

B4 valve it seemed admirably adapted for use in conjunction with a hot wire microphone.

The next circuit (Fig. 9) shows the arrangement we are using this evening. It requires very little explanation. One 12-volt battery supplies current for all circuits with the exception of the plate circuit. The full 12 volts is applied through the primary *T* of a transformer (wound to a resistance of 222 ohms), a milliammeter and the Wollaston wire filament of the hot wire microphone. A potentiometer across half the accumulator supplies the opposing E.M.F. for the zero shunt. A 4-volt tapping from the same accumulator provides the current for the secondary circuit of the relay. The secondary of the transformer *T'* is wound to a resistance of 9,600 ohms. The plate circuit of the valve includes a 75-volt H.T. battery, a delicate galvanometer, and the primary windings of the relay. The resistance *R* included in the zero shunt circuit is adjustable between the values of 100 and 666 ohms.

The selectivity of this method of audio-resonant selection was then put to the test, signals were received by Mr. Child on the outside aerial, and then badly jammed by three volunteer transmitters operating the morse keys of the "interference tester," and it was shown that either these or any of the other signals could be picked out from the medley of noises, and recorded by means of a "siphon recorder."

To make the recorded signals visible to the audience the recorder movement was magnified and thrown on the lantern sheet.

Before bringing this paper to a conclusion, there is one other hot wire application which should be mentioned. In 1907 A. Kœpsel* patented a relay which bears a strong resemblance to Tucker's hot wire microphone. He also employs a hot wire in one arm of a Wheatstone bridge, this is stretched between two supports, in front of but not in contact with one surface of a mica disc, a slot is cut in the disc so that when the latter is in one position, a surface of mica is presented to the whole length of the hot wire. A slight rotation of the disc replaces the mica by an air space, the effect is to regulate the heat radiated from the hot wire, and so to vary its resistance. This small rotation is applied electromagnetically by the currents which it is desired to relay.

The sensitivity is greatly increased by allowing the movements of the disc to cover one arm of a bridge while uncovering the other

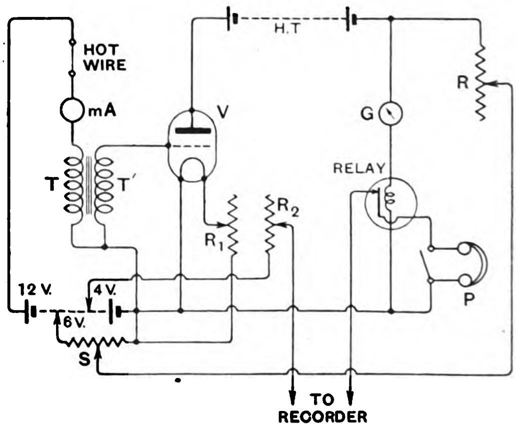


Fig. 9.

arm. Consideration of this device suggests the possibility of the employment of two hot wire microphones placed at suitable distances apart in a resonator, and forming

* "A Sensitive Valve Relay," *Wireless World*, Vol. XIX., 11th August, 1926.

* Kœpsel, British Patent No. 18,238 of 3rd September, 1907.

two arms of a Wheatstone bridge circuit. Or again the pulses of air into and out of a resonator might be employed to operate the mica vane of a Kœpsel relay.

When receiving C.W. signals by heterodyne a very small change of frequency produced by a movement of only one or two divisions on the scale of a .0005 condenser is sufficient (if the loudspeaker is correctly distanced from the resonator) to tune a station completely in or out. As far as I can judge from the comparatively few tests which I have made, reception would appear to be quite free from atmospherics of average strength, and to my mind this is all that we can expect from the system. So long as the atmospheric disturbances are only of the same order of magnitude as the signals, the great majority of them at least are quite perfectly eliminated; but it must be obvious that neither this method nor the "Acoustat" are likely to be of any use in dealing with powerful static discharges which momentarily bias the grid of the detector valve, often sufficiently to paralyse it so that it ceases to function. The cure, if there is one, for these static disturbances, must obviously be applied on the aerial side of the detector.

By aid of audio-resonant selection I think it may be possible to open up the already overcrowded ether to a great many more stations. If the audio-frequency notes of the stations are fixed at the transmitting end either by the employment of tonic train, or musically modulated carrier wave, I see no reason why many more stations should not be squeezed into the wavebands not at present employed for Broadcasting (before they are all appropriated for that purpose) and allowed to overlap their signals.

At the receiving station any one of these signals could be received by a hot wire microphone and resonator or a number of resonators could be employed, each tuned to a different station, and all the signals recorded simultaneously.

The system would also appear to be applicable to wired wireless, and to multiplex line telegraphy.

In conclusion I wish to thank my assistant, Mr. Harwood, for his skilled help in preparing the experiments; Mr. Child for so kindly bringing his receiving set and getting signals for us this evening; Messrs. Lissen for the loan of the H.T. batteries; also the lanternist who has been showing the slides for us all the evening.

DISCUSSION.

Mr. F. H. Haynes: Although certain of the fundamentals dealt with by Mr. Blake are old, he has covered ground which to many of us is entirely new. It is the picking up of the threads of former experiment and weaving them together to give new results that constitutes progress. As the paper covers new ground I can offer no useful comment and I rather search for applications to which the effects demonstrated to us this evening can be applied. It is possible that the note selecting properties of the hot wire microphone combined with the adjustable resonator might be used to analyse loud speaker response to various frequencies though the temperature fluctuations would not of course be uniform for any given amplitude with changes in frequency. The connection between mechanical and electrical resonance which has been so successfully developed has no doubt many useful applications. This is not the first time that Mr. Blake has shown to us results dependent for their success upon sheer manipulative skill and our thanks are due to him for presenting to us a new line of development.

Mr. Maurice Child: This is the first opportunity I have had of seeing Mr. Blake's experiments and I feel that he has done a great deal of valuable work. I think it is useful work because we are inclined to-day to spend most of our time on this miserable broadcasting business—if I may put it that way—and we are forgetting the other side of wireless work to a very great extent, I mean the very important side of telegraphy. After all, telegraph work at high speeds has got to proceed, but I find that very little attention is paid to it to-day in the Press. Most publications are concerned with broadcasting, but Mr. Blake has brought us back to the very important question of the selection of notes for telegraphic work and fairly high speed work. The station we heard to-night was Ongar and the speed of transmission was about 30 to 35 words per minute (I should not think it was much more than that because it would not have been recorded with this particular relay) but it is obvious that with a little trouble improvements can easily be made and a relay obtained which would be absolutely reliable when working at higher speeds. I think we have got to a stage now with this note selection when we can really say that atmospheric disturbances for telegraphic purposes can be practically eliminated. Mention has not been made of the fact that by combining this apparatus with a suitable limiting arrangement of high frequency valves, we have a pretty complete system for the elimination of atmospherics. If atmospherics come in very strongly indeed, far above the signal strength on the aerial, they can be "limited" by dimming the filament of the valves and in other ways so as to reduce their strength before we come to the

actual amplification of the final note by its selection with the hot wire selector which Mr. Blake has designed. There is one other thing which I should like to mention. I notice that Mr. Blake rather prefers to select notes of the order of 300 or 350 cycles. At the moment it occurs to me that that is rather unfortunate because the type of telephone required for energising the hot wire usually responds best at frequencies round about 900 cycles and therefore there must be some loss in efficiency because of this. I imagine there will be some little difficulty, perhaps mechanical, in getting an instrument to respond at, say, 1,000 cycles, but it is all a matter of delicacy of adjustment of the resonating column of air. That, however, may be easily got over because it is a mechanical detail. If we can get a series of fixed resonators set up it would be very useful from a telegraphic point of view. Thus, with a series of such resonators we can quickly switch over and try one after the other and see which is free. If we can do this we should have a pretty useful system for selection without much delay in the actual telegraphic work. Mr. Blake has taken an enormous amount of trouble to come here to-night and bring down all this apparatus, and personally I have enjoyed listening very much to his lecture.

Mr. E. Kilburn Scott: What one might call the psychological factor of Mr. Blake's work, interests me more than the scientific, because his record shows once again the falsity of the assumption held by so many that academic training is a necessary preliminary to scientific research. He is also an example of one who was helped by a father at an early age to make scientific apparatus and experiments, and thus gained adaptiveness in improvising scientific apparatus which is so useful.

The late Mr. Duddell, President of the Institution of Electrical Engineers, was such another in that he developed the oscillograph at an early age and it was partly due to a father who helped and encouraged his experimental work.

The most creative time of life is in the 'twenties and 'thirties, and as each generation produces only a few who are capable of creative scientific work, it is necessary that those who have that special ability should be discovered and encouraged at the right time. Far too many young men are being herded through routine courses of study and examinations in which bookiness and memorising are emphasised at the expense of craftsmanship and the development of original creative talent.

To put it bluntly, I believe that more useful creative work is likely to come from types such as Duddell and Blake than from those who have many academic distinctions.

I take it that Mr. Blake is aiming at eliminating the trouble with atmospherics when receiving wireless messages from overseas. During a recent transmission from Schenectady, I noticed that the announcer's voice was quite clear, whereas the music was not, especially in the high notes. Is it right to assume that atmospherics have less effect on lower tones, for example would a song by a contralto be received better than one by a soprano? Tests on these lines might be useful.

Mr. E. H. Robinson: I should like to ask Mr. Blake about one point with regard to the very interesting subject he has dealt with this evening. The thing that naturally puzzles me is what advantage acoustic selectivity has over electrical selectivity? You can get audio-frequency tuning with audio-frequency tuned electrical circuits in an exactly analogous manner to the acoustic resonator, and I am wondering whether Mr. Blake can point out any advantage in using acoustic resonators over electrical resonators. I have had no experience of these acoustic resonators myself and what I have learned to-night has been extremely interesting. On the other hand, I have had a fair amount of experience in electrical audio-frequency tuning, and I am able to pick out one station from a whole lot, and it is for this reason that I should like to know whether the acoustic method has any definite advantages. It seems to me that we are introducing slightly cumbersome methods in departing from electrical tuning but I may be wrong and I should like Mr. Blake's observations on this point.

Mr. G. G. Blake, replying to the discussion, said: I would like to reply first to the last speaker. With regard to the difference between audio-resonant selection and electrical methods of tuning. Let me say at once that they do not come into conflict at all. My idea is as follows: First of all to get the maximum amount of selectivity possible by the ordinary electrical methods. If you can get all that is necessary in that way, well and good; and there is no need to trouble about audio-resonant selection. On the other hand, if having got the maximum amount of selectivity possible by electrical methods of tuning, you still find stations are jamming one another to such an extent that you cannot separate them out with any ordinary form of receiver, then is the time to make use of some such method as this. I do not suggest that this method is in any way a rival to electrical tuning, but it is an auxiliary method. Mr. Haynes mentioned that this might form a way of testing loud-speakers, and I think there may be a possible application for the hot wire microphone and resonator in making such tests. We might be able to find the predominant notes prevailing in certain loud-speakers by this method. Mr. Child mentioned high speed telegraphy. I quite agree with him as to the possibilities of the hot wire method in this direction. My experiments have, as you can see, been carried out with home-made apparatus, and so far as I can judge, the hot wire appears to follow almost any speed of signals. It does not seem to miss anything as far as I can tell. Mr. Child made a most valuable suggestion when he pointed out that "limiting devices" could be used in conjunction with this apparatus in order to reduce the effect of atmospherics. Mr. Child evidently appreciated the point that this apparatus is not in any way intended as a rival to electrical tuning but that one should first tune electrically and then obtain still further selectivity by this method. Mr. Child discussed the problem of frequency and raised the question, to which note should the resonator be attuned? The resonators you see on the table are quite crude in construction. The plungers are made of cardboard packed with cotton wool and very sharp tuning can hardly be expected. With more perfectly made resonators, however, I see no reason why one should not be

able to work over a wide range of frequencies. I have merely used the frequency which I found best for this particular piece of apparatus. Mr. Kilburn Scott made some very kind remarks and I agree that many of us owe a great deal to our parents for the help they have given us in our early days. I personally owe a great debt of gratitude to my parents which I gladly acknowledge. Mr. Bevan Swift mentioned the Southern Railway, I do not know exactly what he wants me to do. Does he suggest that we should turn our tube railways into a system of electrical resonators with huge hot wire microphones at the openings of the tubes ? I do not see how we are to apply audio resonant selection to the railways, but of course his remarks were only jocular and not intended to be taken seriously.

The President (General Sir Capel Holden, F.R.S., M.I.E.E.,) in proposing a vote of thanks, said : I am sure you will all agree with me that we have had a most interesting lecture from Mr. Blake. He has opened up a new field for thought and also for experiment, and I can only hope that he will bring his experiments to a very successful issue. When I say successful issue, I am not thinking of Mr. Child and his telegraphy, because there are only a very few people, comparatively speaking, interested in telegraphy. I think the public generally are interested in broadcasting and I refer to it because I want to suggest to Mr. Blake that if he could have tried some of his apparatus on the relay which the B.B.C. gave us last night, which consisted of atmospherics and a little music from America in the background, and if he could have given us the music without the atmospherics, then the B.B.C ought to take him and put him into one of its highest salaried posts.

Mr. Blake acknowledged the vote of thanks, and added : Before I sit down I ought to mention that perhaps Mr. Child may be willing to tell you a few things about his set, to which I have already referred and which is rather unique in construction. There are some points about it which I think will be of interest.

Mr. Child : This particular set which I asked Messrs. Henderson, of Fulham Road, to make for me is an endeavour to try and get something which will interest probably a good many of us here. It is nothing very special as regards circuit arrangements, but it is interesting as an example of a complete two-valve receiver employing the comparatively new KL1 valves worked from 50 cycle 200 volt supply. There are no batteries associated with the receiver at all beyond the little grid battery inside. To make sure that the signal strength would suit Mr. Blake's apparatus to-night I had to bring down a small experimental low frequency amplifier so as to have a margin of strength for him to play with, because I did not know exactly what he would require. The only addition that has been made is a little rejector circuit which I have put direct into the aerial for the purpose of cutting out 2LO.

Abstracts and References.

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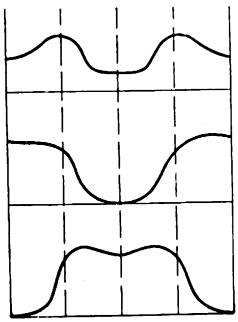
PROPAGATION OF WAVES.

La Notion Experimentale d'une Surface de Référence dans la Propagation des Ondes Courtes (Empirical idea of a surface of reference in the propagation of short waves).—R. Bureau. (*L'Onde Electrique*, 6, 64, April, 1927, pp. 168-169.)

Communication made to the French U.R.S.I. meeting, June, 1926. From a series of observations carried out on board the *Jacques Cartier* (*C.R.* 180, 2,025, 1925) and the *Jeanne d'Arc* (*O.E.* 5, 53, 1926) the author concludes that the greater part of the diverse phenomena found in the propagation of short waves can be referred to a regular variation of a general simple character, compared to which the divergences that are found on certain days may be regarded as accidental disturbances.

Whatever the wavelength (at least between 25 and 115 metres, the range covered in this investigation), the diurnal variation of signal intensity at a given distance from the transmitter presents two minima, which can reach complete extinction. One generally occurs somewhere about mid-day and may be called the day minimum, the other the night minimum. The former becomes more pronounced as the distance increases, as the wavelength increases, and as summer approaches; the latter becomes marked as the distance and wavelength diminish and as winter approaches. One of these minima may flatten out and the two maxima on either side join together, giving the diurnal variation the appearance of a wave with a single undulation and hiding its double undulatory character.

Plotting the three variables: distance, time of day, and signal strength, yields surfaces whose

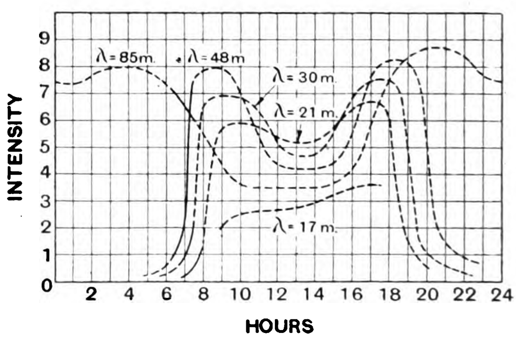


sections all present these same general characteristics. The figure shows three extreme types of surface section; a section of given shape being obtainable by varying indifferently the distance, the time of day, or the wavelength.

Disturbances of this surface can be introduced by the latitude, the orography, and the atmosphere, and before they can be studied, must be isolated from the variations coming simply from the general phenomenon represented by the surface of reference.

Remarque sur la Propagation des Ondes Courtes à Distance Fixe (Note on the propagation of short waves over a given distance). — A. Jouffray. (*L'Onde Electrique*, 6, 64, pp. 170-172, April, 1927.)

M. Bureau has set out the laws of the diurnal variation of the signal strength of short waves as a function of the distance and time of day and shown the existence of two maxima (morning and evening) and of two minima (day and night).



The isolated experimenter, however, relying only on his own observations and forced to regard the distance as a constant, is able to study these same laws by taking for variables the time of day and the wavelength (listening to several emissions quasi simultaneously emanating from the same region). He will find that after the night minimum the emissions appear in general in the order of decreasing wavelength, while in the evening after the second maximum they disappear in the order of increasing wavelength, showing that the maxima are not simultaneous for the different wavelengths but are produced successively. Thus plotting the time of day as abscissæ and signal strength as ordinates, the following graph is given for a distance of about 400 kilometres.

The curves are drawn in only approximately and the author is of the opinion that it would be of great interest to verify the non-simultaneity of the maxima with different wavelengths and find their position accurately by prolonged tests bearing on the two branches of the curves including the same maximum. These same tests would enable the relative values of the maxima to be determined (the evening one generally appearing the higher) as well as the values of the day minima. Thus one would arrive at a definition of the normal law of short wave propagation and then be in a position to broach the study of the perturbations, which is likely to be more fruitful in both theoretical and practical results.

ANOMALIES DE LONGUE DURÉE DANS LA PROPAGATION DES ONDES COURTES (Anomalies of long duration in the propagation of short waves). — R. Bureau. (*Comptes Rendus*, 184, 18, pp. 1078-1080, 2nd May, 1927.)

Experimental study of the propagation of waves between 20 and 115 metres led the author in June, 1926 (*O.E.*, April, 1927, see abstract above) to point out that this propagation is subject to a regular law. According to the law the signal strength of a wavelength λ at a distance d presents two minima: one towards mid-day which is more pronounced as λ and d increase, and the other towards midnight which becomes more marked as λ and d diminish (if d is sufficiently great for the direct ray to be absent), also either of these minima can be attenuated and practically disappear for suitable combinations of the values of d and λ, so that for each distance there are waves that are propagated by day and not by night.

Similar results were arrived at in America at the same period (Heising, Schelleng and Southworth, *Proc. Inst. Radio Eng.*, October, 1926) and were explained as follows: the day minimum is due to absorption caused by ionisation, the effect of which increases with the wavelength, while the night minimum is due to an insufficient curvature of the rays, the curvature decreasing as the wavelength diminishes, and thus the increase in ionisation due to solar radiation in the layers of the atmosphere where the waves travel suffices to explain the law given above.

The results of observations in France over distances of from 10 to 1,500 kilometres have persuaded the author that this law, which he denotes by A, is not only disturbed by accidental and irregular phenomena, but that there is superimposed upon it sometimes an effect of long duration which goes on increasing from week to week. This action, called B, only makes itself felt on pretty short wavelengths (less than 50 metres) without appearing seriously to affect longer ones. Its effect is to reverse in some way that of A, so that, for instance, waves of 30 metres appear earlier before sunrise than waves of 48 metres, and waves of 20 metres present an extinction at mid-day while those of 30 metres continue to be propagated freely. It is as though, beyond a certain limit, the shortening of the wavelength improved night propagation and was less favourable to day propagation.

The author states that these anomalies (as well as others) are best explained by supposing the existence of two ionised layers at altitudes h and H (where $H>h$). The law of propagation A would be due to the first layer, which would be very sensitive to solar action. The propagation of type B would be controlled by the layer H for waves whose curvature is sufficiently small for them to traverse h. The rays of a wave λ_1, reaching H, could be brought back to the ground before the rays of a wave λ_2 longer but entirely refracted by h. This could happen if the layer H is less sensitive to the diurnal variation than the layer h. Further, the rays refracted by H will be equally refracted on the return journey by the layer h and deviated upwards: this phenomenon will be the more perceptible the more ionised h is and the greater the distance. Thus can be explained why it is that at mid-day the wave of 30 metres is received while that of 21 metres no longer comes through when the distance *exceeds* some hundreds of kilometres.

The study of the variations of terrestrial magnetism has led to supposing the existence of two ionised layers, one at an altitude of 50 kilometres presenting marked diurnal variation and the other at an altitude of 90 kilometres localised in two large caps around each pole. The author states that the existence of these two layers would accord entirely with the mechanism suggested here to explain these long period anomalies in the propagation of short waves that experiment reveals.

NOTE SUR CERTAINES ANOMALIES DANS LA PROPAGATION DES ONDES COURTES (Note on certain anomalies in the propagation of short waves.)—R. Bureau. (*L'Onde Electrique*, 6, 61, January, 1927, pp. 52-55.)

The meteorological reports wirelessed from the two ships, the *Jacques-Cartier* and the *Jeanne-d'Arc*, making successive journeys between France and America, have been received regularly in Paris since 1925. The ships transmit simultaneously on two short waves, one in the neighbourhood of 60 metres and the other about 30 metres. Up to last autumn it had always been found that the longer wave was received much better during the night and the shorter wave by day, but since October this has no longer been the case. Waves of the order of 20 to 30 metres cease to arrive in the Paris district except from relatively small distances (of the order of 1,000km.), so that waves of 60 to 75 metres appear by far the more favourable even at midday. This is the case not only with the ships, but also the daily meteorological report from Washington on 24 metres at 21 h. 30 G.M.T., received regularly in September, is completely inaudible since October.

In order to find out whether the phenomenon is only local and confined to Paris or whether it extends also to other parts, inquiries as to the reception of these short waves were made at Bergen, in Norway, and Rabat, in Morocco, with the result that reception there was found to be fairly similar to that obtained previously in Paris. It might thus be concluded that the anomaly observed in Paris since October, 1926, is of a purely local character. However, from one month to the next, it is found to gain in extent and gradually affect the observations in Morocco. For instance, the Washington signal at 21 h. 30 which was received normally at Paris in September, but not at all since, was heard regularly at Rabat with the same intensity up to 10th October, and then disappeared until 20th December, since when it has been irregular and too faint to read. The anomaly is still less marked than at Paris, but it looks as if it were beginning to reach Morocco making itself first felt in waves of the order of 24 metres.

The investigation is being continued.

THE ABSORPTION OF RADIO WAVES IN THE UPPER ATMOSPHERE.—E. O. Hulburt. (*Physical Review*, 29, 5, May, 1927, pp. 706-716.)

The following abstract is given: Recent measurements have shown that radio waves below 150

metres fall off in intensity faster than required by an inverse square law for distances up to 1,000 miles. This points to absorption of the wave by the medium, in this case the upper atmosphere. The absorption of the waves variously polarised is calculated on the assumption that it results from collisions between the electrons and molecules of the atmosphere. With reasonable average values of the electronic and molecular densities, the amplitude A of the wave λ cms. at a distance x cms. is $A = ax^{-1} \exp. (-11.8 \times 10^{-16} \lambda^2 x)$, theoretically valid for waves from 16 to 160 metres to distances of 1,000 miles. This agrees well enough with the scant range and intensity data, and it is pointed out that an extension of these data may lead to more exact knowledge of the overhead electronic and molecular pressures. From the absorption curves interesting possibilities appear of polarisation of waves in the broadcast band 200-600 metres.

EXPERIMENTAL CONFIRMATION OF THE INFLUENCE OF A LOW-RESISTIVITY LAYER SUBSOIL ON THE FORWARD INCLINATION OF RADIO WAVES.—J. Cairns. (*Journ. Washington Acad. Sc.*, 17, 10, pp. 264-269, May, 1927.)

The author summarises his paper as follows :—

Over soil, the mean resistivity of which had been measured *in situ* down to depths of 60 to 100 metres, and which consisted of a layer of sand of an exceptionally high resistivity over a layer at no considerable depth of very low resistivity, radio waves of wavelength 1,250 metres were found to experience no forward inclination. This is regarded as being more definite proof than has hitherto been given of the effect of ground-water or a low-resistivity layer a short distance below the surface, owing to the greater precision of the resistivity measurements of the undisturbed soil.

The apparatus employed is described and the observations are tabulated.

HIGH ANGLE RADIATION OF SHORT ELECTRIC WAVES.—S. Uda. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 377-385.)

An account of experiments in the field distribution due to a straight vertical unloaded antenna operating at one of its harmonics. Short waves of 2.66 metres were employed and observations were made with the antenna both grounded and ungrounded.

The results are also given of tests on a new wave projector designed by the author with special reference to high angle radiation of short waves.

RADIO PHENOMENA RECORDED BY THE UNIVERSITY OF MICHIGAN GREENLAND EXPEDITION, 1926.—P. Oscaryan, Jr. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 425-430.)

Experimental proof was obtained of the fact that when a receiving station, working on 50 metres or under, is placed at the foot of a hill or mountain of greater height than 17° from the station level, then signals are screened off from the receiver. This fact is thought to bear on wave propagation theory. It would also appear that atmospherics in the Arctic are the overflow from more harassed lower latitudes, since they were not observed until the station had been removed from its screened position. Another point noted is that the distance within which "brute force" signals may be heard is greatly increased at sea.

There is to be another expedition, planning to remain up there all during the winter of 1927-28. The writer, who will be in charge of radio, would be glad to co-operate with anyone who wishes to collect comparative data or would like to suggest some particular field of radio to explore.

RADIO TELEGRAPHY AND THE ECLIPSE OF THE SUN.—O. F. B. (*Eclipse Supp. to Nature*, 18th June, 1927, pp. 85-88.)

ÜBER DIE IONISATION DER ATMOSPHÄRE UND IHREN EINFLUSS AUF DIE AUSBREITUNG DER KURZEN WELLEN DER DRAHTLOSEN TELEGRAPHIE (On the ionisation of the atmosphere and its influence on the propagation of short wireless waves).—H. Lassen. (*Telefunken Zeitung*, 58, 44, pp. 26-35.)

A more popular version of the author's theoretical paper of this title that appeared in *Zeitschr. f. Hochfrequenz.*, 28, 4 and 5 (these Abstracts, *E.W. & W.E.*, February, 1927, p. 115), giving the results there obtained, but omitting the mathematics.

PROPAGATION OF SHORT WAVES AROUND THE EARTH.—(*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 341-345.)

Translation of Herr Quäck's article in the December number of the *Zeitschrift für Hochfrequenztechnik*.

WIRELESS TRANSMISSION AND THE UPPER ATMOSPHERE.—(*Nature*, 7th May, 1927, pp. 679-680.)

Report of Prof. Appleton's discourse at the Royal Institution, 29th April, 1927.

MAGNETIC STORMS AND WIRELESS TRANSMISSION.—(*Electrician*, 6th May, 1927, p. 496.)

A letter from Mr. Sreenivasan, of the Indian Institute of Science, referring to Prof. Appleton's article in the *Electrician* of 11th March, where the effect is discussed of an increase in the charged ions in the upper atmosphere on radio wave transmission.

According to Sir Joseph Larmor's suggestion that a magnetic storm is due to an incursion of free electrons into the upper atmosphere and all the regular ray paths are twisted out, the signals of the England-Canada beam service, reported to have been almost completely blocked during the magnetic storm of October, 1926, should have been heard at some other part of the earth, for which, unfortunately, no evidence is forthcoming.

With reference to long wave transmission, the increase in the number of electrons should mean an increased reflection co-efficient, but the writer again observes that there does not seem to be any support for this from available published data, and raises the question as to whether long waves go into the disturbed higher regions at all, but are bent at lower regions that are comparatively unaffected by the changes in ionisation higher up.

ACTIVITÉ SOLAIRE ET PROPAGATION DES ONDES (Solar activity and wave propagation).—G. Pickard. (*L'Onde Electrique*, 6, 62, February, 1927, pp. 91-96.)

The reception of short waves is found to be perceptibly influenced by solar activity, like that of lower frequencies, but while low frequencies (15 to 25 kilocycles) are always attenuated by an increase of solar disturbance, it is found that, at least in the band of 8 to 9 megacycles, reception becomes stronger as the sunspots increase in size. This is thus another of the many phenomena that becomed reversed as one passes from the reception of lower to higher frequencies (*cf.* effects on reception of 1925 eclipse, *Proc. Inst. Radio Engineers*, October, 1925, p. 539).

Graphs are reproduced showing the relation between the reception of three widely-spaced bands of frequency and the variation of sunspots, also between the reception of a distant station working on 1,330 kilocycles and the variations of terrestrial magnetism.

One would expect these relations obtained at Washington between solar activity, magnetic disturbance and reception, which are best defined between about 500 and 1,500 kilocycles, to exist simultaneously over the whole earth, and the author would be glad to compare his results with similar ones made in Europe.

DISCUSSION ON THE CORRELATION OF RADIO RECEPTION WITH SOLAR ACTIVITY AND TERRESTRIAL MAGNETISM. — J. Dellinger. (*Proc. Inst. Radio Engineers*, 15, 4, April, 1927, pp. 326-329.

Discussion of Mr. Pickard's paper that appeared in these Proceedings of last February, pp. 83-97.

ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY.

STUDIES ON RADIO-ATMOSPHERIC DISTURBANCES—(1) DIRECTIONAL OBSERVATIONS AT TOKYO. —J. Obata. (*Journ. Inst. Elect. Eng., Japan*, No. 465, pp. 372-379.)

A preliminary account of the observations of the direction of atmospherics that are being carried out at Tokyo, begun in July, 1926. The apparatus employed is a simple radiogonimeter. The frame antenna is 5 ft. square and has 60 turns of thin stranded wire wound with ¼ in. spacing and is tuned to a wavelength of 10,000 metres. With suitable amplification, records of atmospherics are obtained by means of a high frequency oscillograph: directing the frame to various azimuths, the number of atmospherics per eight seconds is found in each direction.

Although it would be very premature to draw any definite conclusion from observations only extending over a short period of time as to the nature of such a geophysical phenomenon as radio-atmospheric disturbance, which appears to suffer the influence of various causes, yet the results so far obtained seem to indicate that the majority of the atmospherics observed at Tokyo come from a definite region, which varies according to the season.

The apparent direction of arrival of most atmospherics at Tokyo during summer and autumn, when they are most prevalent, are given in the following table:—

July, Aug.	N.W.—W.N.W.	Oct. S.S.W.
Aug., Sept.	W.N.W.—W.	Nov. S.S.W.

These results, compared with those obtained by Nakagami and other at Osaka, indicate that the origin of atmospherics in summer and the beginning of autumn lies in the mountain region of Honshu (Main Island) of Japan.

A STATISTICAL STUDY OF THE EFFECTS OF THE ATMOSPHERIC - ELECTRIC ELEMENTS ON BROADCAST RECEPTION.—J. Cairns. (*Terres. Mag. and Atmos. Elect.*, 32, 1, March, 1927, pp. 11-16.)

An attempt is made to correlate the variations in broadcast reception with the variations of the atmospheric-electric elements, positive and negative conductivity, and potential gradient. Two analyses are given, the one dealing with the results obtained for all days, regardless of the local disturbing effects of smoke, rain, etc., on the atmospheric-electric elements, and the other dealing with the results from "selected" days, that is, days that are considered to be free from any such local effects.

The result of the first analysis shows that when the conductivity, both positive and negative, is subnormal there is a greater probability of better signal reception; the potential gradient, apparently, has little effect.

From the analysis for "selected" days, which is considered the more valuable, it appears that the positive conductivity has little effect on the received signals, whereas when the negative conductivity is low the signals are stronger; also, better signals are received when the potential gradient is high.

MESURES DE LA CONDUCTIBILITÉ ÉLECTRIQUE DE L'ATMOSPHÈRE DANS LA RÉGION DU PÔLE NORD (Measurements of the electric conductivity of the atmosphere in the region of the North Pole).—MM. Malmgrõn and Běhounck. (*Comptes Rendus*, 184, pp. 1185-1187, 16th May, 1927.)

The results of observations made during the Amundsen expedition are given, showing the electric conductivity of the atmosphere at the Pole to be of the same order of magnitude as that found in Central Europe, at the same latitudes, and with the same predominating unipolarity. These results are contrary to the hypothesis which looks for an afflux of negative electricity in the North Pole region, as a consequence of Bauer's magnetic measurements, unless the afflux in question consists of electrons that are too rapid, which, according to Swain, are no longer able to ionise.

ON THE ELECTROSTATICS OF THE THUNDERSTORM. —A. Simon (*Physical Review*, 29, 5, May, 1927, p. 754.)

Abstract of a paper presented at the Los Angeles meeting of the American Physical Society, March, 1927.

The action of the storm cloud is shown to be

analogous to the generation of charges and potentials by rubbing together two dissimilar substances, *i.e.*, the fundamental experiment of frictional electricity. The generation of potentials and electric stresses by precipitation of charged rain and by the inductions of charges at the earth's surface is discussed. It is shown that the "impulsive rush" lightning discharge of Lodge is electrostatically impossible. A relation between the change of gradient in an area, the polarity of the overhead cloud is developed. Approximate numerical relations between gradients, charges, and potentials are deduced.

PROGRESSIVE LIGHTNING.—C. Perrine. (*Nature*, 4th June, 1927, p. 816.)

A letter referring to Prof. Boys's comments on the phenomena of "Progressive Lightning" in *Nature*, of 19th February last (these Abstracts, *E.W. & W.E.*, April, 1927, p. 245), followed by a further note from Prof. Boys.

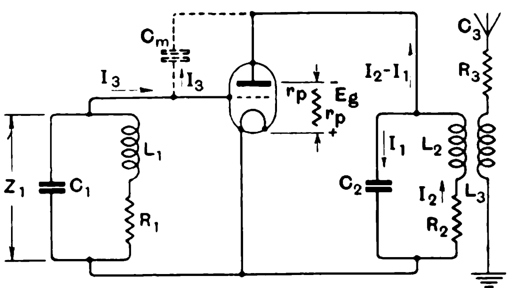
MESURES SUR LES GROS IONS À PARIS (Measurement of large ions at Paris).—J. MacLaughlin. (*Comptes Rendus*, 184, pp. 1183-1185, 16th May, 1927.)

The number of large ions, which is found to be closely related to the distribution of factory chimneys, undergoes daily variation characterised by two maxima and two minima, similar to that found in the case of dust particles at London. It is thought probable that the diurnal variation of large ions, the electric field, and particles of dust, is due to the same causes. Also an *annual* variation of large ions is found of the same amplitude as that ordinarily obtained for the terrestrial electric field.

PROPERTIES OF CIRCUITS.

THE TUNED-GRID TUNED-PLATE CIRCUIT USING PLATE-GRID CAPACITY FOR FEED-BACK.—J. Dow. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 397-400.)

Equations are developed showing the conditions for oscillation in the following circuit which has been recently in favour for short-wave transmission.



SELECTIVITY OF TUNED RADIO RECEIVING SETS.—K. Jarvis. (*Proc. Inst. Radio Engineers*; 15, 5, May, 1927, pp. 401-423.)

In designing modern broadcasting receivers, the radio engineer has three technical objectives: the obtaining of selectivity, fidelity of reproduction, and adequate sound volume. In the ideal receiver these factors will be absolutely independent, a perfecting of any of them contributing to the intrinsic value of the receiver. Unfortunately this state of affairs is not even approached in present practice, a change in design affecting any one of these factors will affect also the other two. A paper on "selectivity" has therefore to consider the entire combination of effects, and show how amplification and quality vary when selectivity is the independent variable. In this paper the term "selectivity" is used to represent the ratio between the wanted signal and an interfering signal, and this ratio is determined and discussed together with its bearing on amplification and quality of reproduction.

ÜBER RELAXATIONSSCHWINGUNGEN II. (On relaxation-oscillations II.).—B. van der Pol, jun. (*Zeitschr. f. Hochfrequenz.*, 29, 4, April, 1927, pp. 114-118.)

An article on this subject appeared in this *Zeitschrift* for last December, pp. 178-184, of which there was an English version in the *Philosophical Magazine*, of November, pp. 978-992 (these Abstracts *E.W. & W.E.*, January, 1927, p. 51.)

Owing to further investigation by the author, both theoretical and experimental, and publications by others on the subject, the first article is here extended and supplemented, the summary of the whole being given as follows:

The behaviour is studied of the solution of

$$L\ddot{v} - R(1-v^2)\dot{v} + \frac{1}{C}v = 0$$

for the two cases

$$(a) \quad R\sqrt{\frac{C}{L}} << 1 \text{ (periodic case)}$$

and

$$(b) \quad R\sqrt{\frac{C}{L}} >> 1 \text{ (quasi-aperiodic case).}$$

The condition (*a*) is characteristic of maintained sinusoidal oscillations, while case (*b*) allows also of a periodic solution that deviates considerably from the sine form. The times of oscillation T_{sin} and T_{rel} in cases (*a*) and (*b*) are given respectively by

$$(a) \quad T_{sin} = 2\pi\sqrt{CL}$$

$$(b) \quad T_{rel} = \frac{\pi}{2} RC$$

The period of the quasi-aperiodic case (*b*) is thus determined by a "time of relaxation," wherefore this type of oscillation is called "relaxation-oscillation." The form of the oscillations in both cases is studied by means of the "method of isoclynes."

Various applications of relaxation-oscillations are described: the multi-vibrator of Abraham and Bloch, a double-grid multi-vibrator, etc. It is further shown that the periodic pole change of an externally excited motor, supplied by a series dynamo rotating with constant velocity, belongs to the type relaxation-oscillations, whereby some difficulties in practice not hitherto understood are explained by means of oscillograms. It is pointed out that, contrary to sinusoidal systems (*a*), the frequency of systems, which left to themselves

execute relaxation oscillations (*b*), can be influenced by outside forces within wide limits (a property utilised by Dr. Dye in his multi-vibrator).

THE THEORY OF THE LINEAR ELECTRIC OSCILLATOR AND ITS BEARING ON THE ELECTRON THEORY.—G. Schott. (*Phil. Mag.*, 3, 16, Suppl. April, 1927, pp. 739-752.)

TRANSMISSION.

ÉTUDE EXPERIMENTALE DU FONCTIONNEMENT D'UN TRIODE EMETTEUR (Experimental investigation of the operation of a triode transmitter).—R. Jouaust. (*L'Onde Electrique*, 6, 65, May, 1927, pp. 200-210.)

The characteristic curves of a triode transmitter of one kilowatt, obtained with reduced filament heating, have enabled the laws regulating the emission of secondary electrons by the grid to be studied. From the results obtained an approximate method is deduced of determining the conditions beforehand under which a triode should function.

APPROXIMATE THEORY OF THE FLAT PROJECTOR (FRANKLIN) AERIAL USED IN THE MARCONI BEAM SYSTEM OF WIRELESS TELEGRAPHY.—J. A. Fleming. (*E.W. & W.E.*, July, 1927, pp. 387-392.)

ELECTRICAL FILTERS.—A. Morrice. (*Phil. Mag.*, 3, 16, Suppl. April, 1927, pp. 801-843.)

Extract from paper given before the Institution of Post Office Electrical Engineers, which includes the use of electrical filters in radio-telephony.

VACUUM TUBES AS OSCILLATION GENERATORS.—D. Prince and F. Vogdes. (*General Electric Review*, 30, 6, pp. 320-321, June, 1927.)

This first part of a serial deals simply with the nature of high frequency circuits.

DISCUSSION ON FIELD DISTRIBUTION AND RADIATION RESISTANCE OF A STRAIGHT, VERTICAL, UNLOADED ANTENNA RADIATING AT ONE OF ITS HARMONICS. (S. Levin and C. Young.)—O. Roos. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 439-443.)

Contribution to the history of the early aspects of the subject, referring particularly to the early work on antenna radiation at shorter than fundamental wavelengths, by John Stone Stone, of Boston, and the German, F. Hack, neither of whom was mentioned in the paper of Messrs. Levin and Young (*Proc. Inst. R.E.*, 14, 5, October, 1926).

SECRET RADIO-TELEPHONY SYSTEMS.—O. F. Brown. (*Wireless World*, 8th and 15th June, 1927, pp. 713-716 and 763-765 respectively.)

A review of the problems involved and solutions suggested.

RECEPTION.

L'ALIMENTATION DES LAMPES BIGRILLES PAR LE COURANT ALTERNATIF (Supplying four-electrode valves with alternating current).—R. Barthélemy. (*Radio-Revue*, June, 1927, pp. 382-386.)

The four-electrode valve is more sensitive to disturbance in the current source than the triode and the methods employed for the latter do not suffice to secure correct operation for the tetrode.

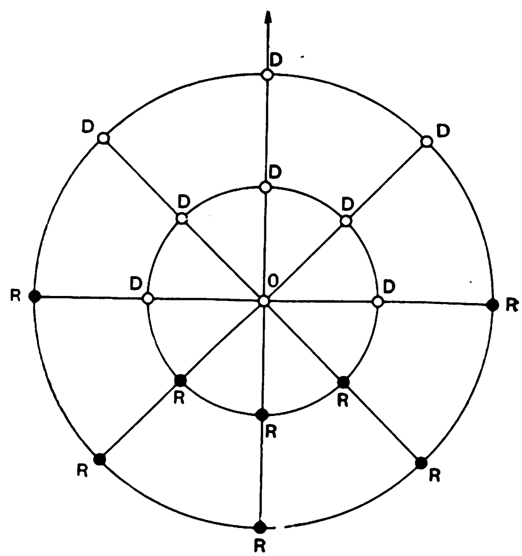
The filament supply is the most difficult, and details are given here with circuit-diagrams of a self-regulating converter, ensuring successful filament heating.

DESIGN AND CONSTRUCTION OF A SUPERHETERODYNE RECEIVER.—P. K. Turner. (*E.W. & W.E.*, May, June and July, 1927, pp. 286, 339 and 402 respectively.)

DIRECTIONAL WIRELESS.

ON THE WIRELESS BEAM OF SHORT ELECTRIC WAVES.—VI. (Direction control of the beam). S. Uda. (*Journ. Inst. Elect. Eng. Japan.* No. 465, pp. 396-403.)

This paper describes a new method of direction control of the short-wave beam, and gives the experimental results. The arrangement of the system for the case of eightfold directionality is shown in the following figure :—



where *O* is the transmitting aerial, *R* are reflectors and *D* directors.

The sixteen conductors, of which half are reflectors and half directors, are arranged around a vertical sending antenna on two concentric circles whose radii are $\frac{1}{4}\lambda$ and $\frac{1}{2}\lambda$ respectively. Maximum energy is radiated in the direction of the arrow. When the length of the *D*s is varied, the radiation in the direction of the arrow changes; so long as the length is larger than $\frac{1}{2}\lambda$, the wave is almost screened and comparatively little energy is transmitted, but when the length is made smaller than $\frac{1}{2}\lambda$, there is a region in which the received energy becomes much increased due to the existence of the rods. If means are provided to control the natural wavelength of the rods, so that the wave may be radiated in any other desired direction,

then a beam of variable directionality can be produced. Thus the wave may be sent into several different directions in any desired order and particularly in rotation. The control of the rods may be effected electrically or mechanically, by push-button device or automatic means, and the beam can thus be rotated without either changing the position of the conductors or revolving a large structure.

The case for 16 different directions has also been investigated, and the polar curve is given. More wave directors may conveniently be arranged along the radial lines to improve the sharpness of the beam in these directions. The interval between these directors must, of course, be larger than $\frac{1}{4}\lambda$ and smaller than $\frac{1}{2}\lambda$.

This type of short-wave radio beacon is quite simple, and is believed to find application in directing ships approaching the shore or guiding aviators flying in the dark.

Émissions dirigées par Rideaux d'Antennes, Antennes en Greque (Directional emission by curtain antennæ; antennæ in the form of the Greek key-pattern).—R. Mesny. (*L'Onde Electrique*, 6, 65, May, 1927, pp. 181-199.)

Lecture given to the S.A.T.S.F., 8th February, 1927.

Two methods of using directional emission are distinguished :—

1. Concentrating the energy in a narrow beam, thereby securing a certain degree of secrecy and reducing interference in communication.

2. Causing a beam to rotate for enabling ships at sea and aircraft to determine their position.

In the first case the energy must be practically nil in the whole of the unused sector, also since the apparatus is fixed it can be of any desired dimensions; while in the second case, there must be a distinctly recognisable energy maximum in a certain direction, but in other directions the radiation need not necessarily be nil or even weak, also since these beacons have to rotate, perhaps in the open air to avoid irregular absorption by buildings, they have to be made as small as possible.

This paper examines the properties of curtain antennæ, for producing such beams. The difficulties of current supply are said to be eliminated by employing curtains made of a single wire, bent in the shape of the Greek key-pattern, supplied with current at its middle point. By modifying these curtains, various kinds of beam are produced, the diagrams of which, obtained by measurement, are shown and compared with those produced by other methods.

A Sensitive Long Range Radio Direction Finder.—R. L. Smith-Rose. (*Journ. Scientific Instruments*, 4, 8, May, 1927, pp. 252-262.)

The author summarises his article as follows :—

A description is given of a single-frame coil type of direction-finder which was constructed for the purpose of taking wireless bearings on long-wave transmitting stations at distances of several thousand miles. The precautions taken to overcome sources of error in these direction-finders are described in some detail, and a brief account is given of some typical results obtainable with the instrument.

VALVES AND THERMIONICS.

Das innere Widerstand der Elektronenröhre (The internal resistance of the valve).—W. Bermbach. (*Zeitschr. f. Hochfrequenz.*, 29, 4, April, 1927, pp. 119-120.)

Assuming the anode current equal to the emission current ($v_g \leqq 0$), the following formula for the internal resistance of a valve is derived :—

$$R_i = \tfrac{2}{3} K^{-\frac{2}{3}} \cdot D^{-1} \cdot x^{-\frac{1}{3}}$$

Where K is the valve constant, D the "Durchgriff," and x the anode current in amps. The equation shows that the internal resistance of a given valve is inversely proportional to the cube root of the anode current.

The influence exerted by the "Durchgriff" on the amplification factor is discussed under the conditions of resistance amplification (high ohmic resistance in exterior part of anode circuit). For a given case it is shown how the internal resistance changes with the grid tension. An explanation is attempted of how it is that $i_a(R_{ext.} + R_i)$ is smaller than the battery tension.

The Internal Action and Principles of Design of Thermionic Valves. — A. Bartlett. (*E.W. & W.E.*, July, 1927, pp. 430-439.)

Lecture before the R.S.G.B. at the Institution of Electrical Engineers, April, 1927.

Puncture Damage through the Glass Wall of a Transmitting Vacuum Tube.—Y. Kusunose. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 431-437.)

The causes of the frequent occurrence of valve puncture in short-wave transmission have been investigated by the writer, and are attributed to the dielectric loss in glass. Precautions to be taken to prevent the damage are enumerated.

The World's Largest Valve.—(*Wireless World*, 15th June, 1927, pp. 743-744.)

Description of the new 100kW valve used by WGY, the General Electric Company's large broadcast transmitter at Schenectady, N.Y.

Les Courbes Potentiométriques (Potentiometer curves).—S. Lwoff. (*Radio-Revue*, June, 1927, pp. 388-389.)

Description of a new method of determining the amplification factor of a triode.

The Characteristics of Tungsten Filaments as Functions of Temperature.—I.—H. Jones and I. Langmuir. (*Gen. Elect. Review*, 30, 6, pp. 310-319, June, 1927.)

The purpose of this article is to present the most accurate data to hand on the characteristics of tungsten filaments in vacuo, at various temperatures, in as convenient and complete a form as possible.

FACTORS INFLUENCING THERMIONIC EMISSION.—A. K. Brewer. (*Physical Review*, May, 1927, p. 752.)

Abstract of a paper presented at the Los Angeles meeting of the American Physical Society, March, 1927.

The thermionic emission from gold is determined in the presence of various gases at atmospheric pressure. Both the positive and negative currents follow the Richardson equation, although there is no semblance of saturation. A distinct proportionality exists between the difference in the values of b_1 (Δb), for the positive and for the negative emission, and for the corresponding differences in the values of T_1 (ΔT). Again, when an emitter, such as iron, is slowly oxidised over, there is a gradual increase in the values of b and T for the positive emission, which is concomitant with a corresponding decrease for the negative emission. When the value of b is the same for ions of each sign, T is likewise the same. The relationship between Δb and ΔT is accounted for by the presence of an intrinsic force at the surface, possessing the properties of a resultant field. The change in T and b accompanying the oxidation of a surface is doubtless due to the presence of the negative oxygen ions neutralising the positive intrinsic field, and upon high oxidation, actually giving rise to a resultant negative field.

DAS ELEKSTROSTATISCHE FELD EINER RAUMLADUNG.—I. (The electrostatic field of a space charge. I.).—O. Emersleben. (*Annalen der Physik*, 82, 6, April, 1927, pp. 713-774.)

Classical valve theory, as it originated about ten years ago, assumes quasi-stationary conditions. Proceeding from given (static) valve characteristics, showing the electronic current as a function of the potential difference between the electrodes, it is sufficient to know the potential difference to know the behaviour of the valve. Further, to study the emission current proceeding from the individual electrons, one starts from purely electrostatic considerations (assumption of constant potential on the electrodes) without needing to take any account of the electrons moved within the valve.

These theories are entirely "macroscopic," but even in papers where the current emitted by the incandescent filament is investigated or space charges are reckoned with (*e.g.*, in the case of double-grid valves) the authors are far from considering the *individual* electrons "microscopically." Even when the production of oscillations of the Barkhausen and Kurz type is explained through oscillations of the space-charges, only their frequencies are calculated, and no one, when considering the field produced by space charges, yet seems to have made the movement of the electrons the object of *quantitative* study. In this "microscopic" investigation, the treatment of electronic *movement* is reserved for a later paper, the present paper calculating the electric field produced by the electrons in a state of rest. The purpose of the long mathematical discussion is to provide an answer to the following question: The n electrodes $E_1, E_2 \ldots E_n$ have each the constant potential $V_1, V_2, \ldots V_n$. At the N points $P_1, P_2, \ldots P_N$ there are respectively the stationary charges $-e_1, -e_2, \ldots -e_N$. What is the potential $\Phi(Q)$ at any point Q of the space R between the electrodes?

GENERAL PHYSICAL ARTICLES.

DISPERSION OF AN ELECTRON BEAM.—E. Watson. (*Phil. Mag.*, 3, 16, Suppl., April, 1927, pp. 849-853.)

An analysis showing how a cathode ray beam, used as an indicator, should be adjusted to work at maximum efficiency.

YEARLY VARIATION OF THE QUANTITY OF OZONE IN THE UPPER ATMOSPHERE.—F. Goetz. (*Beitr. z. Physik d. f. Atmosphäre*, 13, No. 1.)

The quantity of ozone present in the upper air is estimated from the observed absorption suffered by the wavelength 320$\mu\mu$ from the sun. The relative amounts of ozone in the four seasons are found to be, in arbitrary units, 1922, winter, 97; spring, 112; summer, 95.5; autumn, 92; and 1923, winter, 103.5; spring, 115.

At Arosa, where the author's laboratory is situated, changes in atmospheric pressure and in ozone content take place in opposite directions.

SUR LA PERMÉABILITÉ DU FER AUX FRÉQUENCES ELEVÉES (On the permeability of iron at high frequencies).—C. Gutton and I. Mihal. (*Comptes Rendus*, 184, pp. 1234-1237, 23rd May, 1927.)

M. Arkadiew found in his experiments that the permeability varies within wide limits and very irregularly as the frequency is changed. M. Laville, on the other hand, found that the value remains nearly constant. The experiments described here, like those of M. Laville, do not permit the conclusion to be drawn that variations in the permeability of iron exist analogous to the variations of the dielectric constant in the neighbourhood of absorption bands.

L'INFLUENCE DES ACTIONS MÉCANIQUES ET DES COURANTS ALTERNATIFS SUR LES DISCONTINUITÉS D'AIMANTATION DU FER (The effect of mechanical action and alternating current on the discontinuities in the magnetisation of iron).—S. Procopin. (*Comptes Rendus*, 184, pp. 1163-1164, 16th May, 1927.)

BRUISSEMENT DANS L'AIMANTATION DU FER (Acoustical phenomena accompanying the magnetisation of iron). — W. Arkadiew. (*Comptes Rendus*, 184, pp. 1233-1234, 23rd May, 1927.)

In 1919, Barkhausen discovered discontinuity in the magnetisation of some specimens of iron, revealed by noises in the telephone connected to the coil surrounding the specimen. The writer here describes a simple method of observing directly the sounds, which are due to discontinuous deformation of the substance undergoing magnetisation.

THE APPLICATION OF THE METHOD OF THE MAGNETIC SPECTRUM TO THE STUDY OF SECONDARY ELECTRONIC EMISSION.—C. Sharman. (*Proc. Cam. Phil. Soc.* V., pp. 523-530.)

ELECTRIC DOUBLE-REFRACTION IN RELATION TO THE POLARITY AND OPTICAL ANISOTROPHY OF MOLECULES. — PART I. — GASES AND VAPOURS.—C. Raman and K. Krishnan. (*Phil Mag.*, 3, 16, Suppl., April, 1927, pp. 713-723.)

NOTE SUR L'HYSTÉRÉSIS DIÉLECTRIQUE DES SUBSTANCES PHOSPHORESCENTES. (Note on the dielectric hysteresis of phosphorescent substances.)—F. Dacos. (*L'Onde Electrique*, 6, 65, pp. 211-214.)

Brief description of a qualitative investigation leading to the conclusion that hysteresis loss is greatest for the substance that is the most phosphorescent.

ON THE RELATION BETWEEN THE SECONDARY ELECTRON EMISSION FROM NICKEL AND TUNGSTEN AND THE TEMPERATURE. — H. Nukiyama and H. Horikawa. (*Journ. Inst. Elect. Eng. Japan*, No. 465, pp. 424-433.)

THE THERMIONIC EMISSION FROM IRON-ALKALI MIXTURES USED AS CATALYSTS IN THE SYNTHESIS OF AMMONIA.—C. Kunsman. (*Journ. Franklin Institute*, May, 1927, pp. 635-645.)

ELECTRON EMISSION UNDER THE INFLUENCE OF CHEMICAL ACTION AT HIGHER GAS PRESSURES, AND SOME PHOTO-ELECTRIC EXPERIMENTS WITH LIQUID ALLOYS.—O. W. Richardson and M. Brotherton. (*Proc. Roy. Soc.*, A, 115, pp. 20-41, June, 1927.)

A NOTE ON THE THEORY OF ELECTRICAL PHENOMENA IN AN IMPERFECT DIELECTRIC MEDIUM. — H. Nukiyama. (*Journ. Inst. Elect. Eng. Japan*, No. 464, pp. 306-324.)

A CONTRIBUTION TO MODERN IDEAS ON THE QUANTUM THEORY.—H. Flint and J. Fisher. —(*Proc. Roy. Soc.*, A. 115, pp. 208-214, June, 1927.)

A mathematical discussion indicating that by the introduction of a new element into Physics, it appears possible to include in one uniform scheme gravitational, electrical and quantum phenomena.

WAVE MECHANICS AND CLASSICAL MECHANICS AND ELECTRODYNAMICS.—G. Schott. (*Nature*, 4th June, 1927, pp. 820-822.)

LIGHT-TRANSMITTED SOUND BY MODULATION OF MERCURY-ARC RADIATION.—D. Stickbarger. (*General Electric Review*, 30, 5, pp. 261-263, May, 1927.)

ON THE SPARKING POTENTIALS OF GLOW DISCHARGE-TUBES.—J. Taylor. (*Phil. Mag.*, 3, 16, Suppl. April, 1927, pp. 753-770.)

POTENTIAL OF SYSTEMS OF ELECTRIC CHARGES.—C. Wall. (*Phil. Mag.*, 2, 16, Suppl., April, 1927, pp. 660-688.)

IONISATION BY COLLISIONS OF THE SECOND KIND IN THE RARE GASES.—G. Harnwell, (*Physical Review*, May, 1927, pp. 683-692.)

STATIONS: OPERATION AND DESIGN.

UNITED STATES—NEW RADIOGRAM RELAY STATION. —(*Electrical Review*, 17th June, 1927, p. 978.)

Transoceanic traffic is now handled at the Belfast, Maine, receiving station of the Radio Corporation of America, since extensive tests have proved that the reception of European signals is much better there than at Riverhead, on Long Island, where the main receiving station is located. A survey of thunderstorms during the past decade indicates that there are twice as many thunderstorms at Riverhead as at Belfast, and so reception at the former point is more affected; also, while Belfast is nearly north of Riverhead, it lies almost directly on the great circle route from Riverhead to Europe, and is 300 miles nearer the distant transmitters than Riverhead; for this reason the European radio signals are at least 30 per cent. stronger at Belfast. The new station at present houses 12 complete long-wave receiving sets, operating on wavelengths from 8,000 to 23,000 metres in addition to battery and motor-generator equipment. The station picks up European signals on a Beverage unidirectional triple antenna, nine miles long, but only 20 feet above the ground. By means of wave traps and filters the desired signals are taken from the antenna, amplified, detected and again amplified, and then relayed automatically over telegraph lines to the central office in New York City.

UNITED STATES—SHORT WAVE ARMY COMMUNICATION.—(*Electrical Review*, 3rd June, 1927, p. 887.)

Short-wave transmitters are being used by the Army Signal Corps to circumvent static in the transmission of official messages over the Army radio net which connects the War Department with the Corps area headquarters and Army posts throughout the country. The sets are crystal controlled and designed to operate in two frequency bands, one of approximately 4,000 to 4,500, and the other of 8,000 to 9,100 kilocycles.

BULGARIAN WIRELESS CONTRACT.—(*Electrician*, 98, p. 662, 10th June, 1927.)

A contract for the supply of wireless transmitting and receiving stations to the Bulgarian Government for the purpose of placing Bulgaria in direct communication with England, Austria and other European countries, has been secured by the Marconi Company in competition with French and German wireless engineering firms. Among the apparatus to be installed at Sofia is a high-speed transmitter with a power of 10 kilowatts to the anodes and a wavelength range between 36 and 72 metres. This transmitter will be used for communication with Marconi stations in England, through which Sofia will be in touch with the principal cities of the world. The Sofia stations will also contain a high-speed long-wave combined telegraph and telephone transmitter for communication with Vienna, with a wave range of from 2,000 to 4,000 metres, all the necessary electric supply equipment and reserve generating plant being installed under the contract.

TURKEY—NEW STATION.—(*Electrical Review*, 17th June, 1927, p. 978.)

At present Turkey has only one station—" Radio Stamboul," erected at Osmanie, 16 miles out of Constantinople. A new station, however, is being opened this month at Angora, which will be the most powerful in the Near East. It has cost over £100,000. The control of wireless telegraphy in Turkey is in the hands of a limited company in which the Post Office, the official Anatolian News Agency, and the Banque d'Affaires are interested. A licence costs the equivalent of 30s., and a heavy fine is imposed on persons who listen without one.

DITTON PARK RESEARCH STATION.—J. Herd. (*Wireless World*, 15th June, 1927, pp. 740-742.)

Account of apparatus used during the eclipse for studying the propagation of waves and atmospherics.

LE NOUVEAU POSTE D'EMISSION " RADIO-VITUS." —THE NEW TRANSMITTING STATION, " RADIO-VITUS."—(*Radio Revue*, June, 1927, pp. 386-388.)

This station, constructed by M. Vitus, has been set up to broadcast a group of artists and literary men, and transmit to France and beyond " the radiation of French thought and art." A brief technical description is given here of the station, which works on a wavelength of about 310 metres.

MEASUREMENTS AND STANDARDS.

ZUSAMMENFASSENDEN BERICHT. NORMAL FREQUENZEN UND ABSOLUTE FREQUENZMESSUNG (Survey of the subject of standard frequencies and absolute measurement of frequency.)—A. Scheibe. (*Zeitschr. f. Hochfrequenz.*, 29, 4 and 5, pp. 120-129 and 158-162, resp., April and May, 1927.)

The following methods are used for the determination of frequency :—

1. Comparing the frequency of the oscillations with a standard frequency.
2. Measuring the frequency with a standard frequency meter.
3. Calculating the frequency from the wavelength of the oscillations obtained by means of Lecher wires.

Of these three methods, only the first refers the frequency to be measured to an exactly known standard frequency by direct comparison. The other two need the first method to prove their applicability. In the present paper, the methods for obtaining standard frequencies, and comparing and measuring frequency, are only discussed in so far as they meet the present requirements of determining frequency correct at least to some ten thousandths, and therefore wavemeters such as those used commercially are not considered.

A multiple of the frequency unit of 1 Hertz forms the fundamental frequency of a graduation of standard frequencies. As the source of this fundamental frequency of some hundred to thousand Hertz, alternating current from a rotating machine can be employed, or interrupted direct current or a standard tuning fork. Interrupted direct current has the advantage over the other two frequency sources that it yields a frequency sum rich in powerful higher harmonics.

The first part of the paper deals with the production of standard frequencies and is divided into sections as follows :—

(*a*) The standard tuning fork
  (α) The valve tuning fork
  (β) The valve tuning fork as frequency standard.
  (γ) Control by means of the valve tuning fork ; relays.
(*b*) Tuning fork—neon lamp oscillator.
(*c*) The multivibrator.
(*d*) Transmitter with discrete standard frequencies.
(*e*) Synchronisation of standard transmitters.
(*f*) Quartz crystal controlled transmitters.
(*g*) Transmitters with continuous standard frequency graduation.

The second part of the paper is concerned with frequency measurement under the following headings :—

(*a*) Audible frequencies.
(*b*) Medium and high frequency.
(*c*) Standard frequency meters.

A bibliography of the literature consulted is appended.

THE EXACT AND PRECISE MEASUREMENT OF WAVE-LENGTH IN RADIO TRANSMITTING STATIONS. —R. Braillard and E. Divoire. (*E.W. & W.E.*, July, 1927, pp. 394-401.)

Conclusion of an article begun in previous issue, continuing the description of the wavemeter, and then passing on to the method of standardisation and the precision of the measurements.

ÜBER EINE EINFACHE METHODE ZUR INDIREKTEN MESSUNG VON GITTERSTRÖMEN (On a simple method of measuring grid currents indirectly.) —M. v. Ardenne. (*Zeitschr. f. Hochfrequenz.*, 29, 3, pp. 88-90.)

A simple method is given which, for example, in the case of ordinary valves with indicating instruments of sensitivity 10^{-3} to 10^{-4} ampere, permits the measurement of grid currents of 10^{-7} to 10^{-8} ampere. The method depends upon the fact that, as soon as grid current flows, the tension on the grid changes, through the tension drop across an ohmic resistance in the grid circuit, causing the anode current to vary in the well-known way. The presence and direction of the grid currents are found from the variation of the anode current that occurs on bridging over the ohmic resistance in the grid circuit.

ELECTRICAL MEASUREMENTS AT RADIO FREQUENCIES.—S. Brown and M. Colby. (*Physical Review*, 29, 5, May, 1927, pp. 717-726.)

Resistance, inductance, capacity and impedance are measured at radio frequencies with the aid of a valve voltmeter. The experiments described and the data presented illustrate methods of

measurement at radio frequencies that are comparable to the corresponding measurements at low frequencies with regard to both simplicity and accuracy.

The methods of making many radio frequency measurements have been improved: (*a*) By using such a low resistance circuit that the coupling to the source of power could be made very loose. The coefficient of coupling was frequently as low as 1×10^{-6}. (*b*) By using a negligible amount of power from the oscillator, with the result that the E.M.F. induced in the tuned circuit remained constant. The power drawn seldom exceeded 2×10^{-5} watts. (*c*) By employing a sensitive and accurate voltmeter that is independent of frequency with which voltage changes of 0.2 millivolt could be detected.

ETALONNAGE DIRECT D'UN ONDEMÈTRE EN FONCTION DES HARMONIQUES D'UN DIAPASON (Direct calibration of a wavemeter in terms of the harmonics of a tuning-fork.)—F. Bedeau and J. de Mare. (*Comptes Rendus*, 184, pp. 1161-1162, 16th May, 1927.)

NOTES ON RADIO RECEIVER MEASUREMENTS.—T. Smith and G. Rodwin. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 387-395.)

Description of attempts to obtain a basis of comparison for radio receivers of different types, and to co-ordinate the testing of receivers, so that the results obtained may be correlated with broadcasting station performance.

LOUD-SPEAKER TESTING METHODS.—I. Wolff and A. Ringel. (*Proc. Inst. Radio Engineers*, 15, 5, May, 1927, pp. 363-376.)

An account is given of a satisfactory system which makes a written record in two or three minutes of the loud-speaker output measured in pressure of the sound wave. The apparatus used and procedure followed are described under the three headings: "Oscillator," "Sound Pickup and Recording Apparatus," and "Position of Sound Pickup."

AN IMPROVEMENT ON THE "DOUBLE CLICK" METHOD OF MEASURING THE RESONANT WAVELENGTH OF A CIRCUIT.—(*E.W. & W.E.*, July, 1927, pp. 392-393.)

A WIRELESS WORKS LABORATORY.—P. K. Turner. *E.W. & W.E.*, July, 1927, pp. 422-429.)

Paper read before the Wireless Section, I.E.E., May, 1927, describing the equipment of the Laboratory of the Research Department of Messrs. Burndept Wireless, Ltd.

SUBSIDIARY APPARATUS.

A SIMPLE THEORY OF KENOTRON RECTIFIER CIRCUIT.—S. Kanazawa. (*Journ. Inst. Elect. Eng. Japan*, No. 464, pp. 300-305.)

In this paper the action of a single phase kenotron rectifier, supplying an output voltage with a considerably smaller pulsation, is explained, also, assuming that the supplied voltage is of sinusoidal wave-form, the relation between the ratio of working resistance of the kenotron to load resistance and that of supplied to output voltage, is simply obtained.

A RADIO-TELEPHONE LOUD-SPEAKER. E. Braendle. (*Electrical Review*, 3rd June, 1927, pp. 876-878.)

Description of a new form of large diaphragm hornless loud-speaker, for which both rigidity and mobility are claimed.

In the review of 17th June, p. 997, Mr. Tyers comments on this article asking for justification of various statements made.

MISCELLANEOUS.

TELEVISION.—E. Taylor Jones. (*Nature*, 18th June, 1927, p. 896.)

Brief description of the demonstration of television by Mr. Baird between London and Glasgow last month, with additional information as to the method.

Prof. Jones' impression after witnessing the demonstration is that the chief difficulties connected with television have been overcome by Mr. Baird, and that the improvements still to be effected are mainly matters of detail.

REGULAR BROADCAST TRANSMISSIONS. (*Wireless World*, 15th June, 1927, pp. 760-762.)

A list, as complete as possible, of stations likely to be heard in England, giving also the call sign, nominal power, and wavelength.

D. E. H.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPAGADO DE ONDOJ.

PROKSIMUMA TEORIO DE LA PLATA ANTAŬENĴETA ANTENO UZITA ĈE LA MARCONI'A UNUDIREKTA SISTEMO DE SENFADENA TELEGRAFIO.—D-ro. J. A. Fleming, F.R.S.

La teorio estas donita pri la unudirekta tipo de radiado, kiel uzita ĉe la Marconi'a-Franklin'a Unudirekta Sistemo. La unudirekta radio estas akirita per aranĝo de vertikalaj antenaj fadenoj je egalaj distancoj, kaj en unu plato, kun serio de reflektaj fadenoj malantaŭ ili en paralela plato je distanco de unu-kvarona ondolongo.

La teorio de radiado per tia antena aranĝo estas diskutita, kaj esprimoj donitaj por la valoroj de radiado je diversaj anguloj. Laŭ tabeloj, kiuj resumas ĉi tiujn esprimojn, oni montras, ke estas kompleta antaŭena ĵetado de la radiado, kaj kompleta malhelpo de iu ajn radiado malantaŭen. Oni ankaŭ montras, ke estas meniom da radiado ortangule, t.e., en direkto al la plato de la vertikalaj antenoj.

Kurvo de intenseco kontraŭ angula divergo montras serion de interferaj grupoj, analogiaj je tiuj de optikaj eksperimentoj.

RICEVADO.

DESEGNO KAJ KONSTRUO DE SUPERHETERODINA RICEVILO.—P. K. Turner.

Ĉi tiu artikolo estas daŭrigita el du antaŭaj numeroj. En la nuna parto la aŭtoro unue traktas pri l'aranĝoj por refleksi la kombinitan Interfrekvencan kaj Malaltfrekvencan amplifadon, aparte la reakciajn aranĝojn, por lasi la I.F. agordon simila al la aliaj cirkvitoj por " grupa kontrolo."

Oni poste montras la kompletajn cirkvitojn de la ricevilo, kun notoj pri la tipo kaj valoro de la konstrueroj uzitaj.

La sternado kaj konstruado estas poste pritraktitaj, ilustritaj per desegnaĵoj de la ĝenerala sternado, kaj detaloj de diversaj partoj. Fine oni donas notojn pri la ricevilo dum funkciado, kaj pri modifaĵoj kaj sugestoj por plibonigo.

TRAMVOJA INTERFERO KONTRAŬ BRODKASTA RICEVADO.

Redakcia noto priskribanta eksperimentojn lastatempe faritajn pri ĉi tiu temo en Berlin.

VALVOJ KAJ TERMIONIKO.

LA INTERNA FUNKCIO KAJ DESEGNAJ PRINCIPOJ DE TERMIONAJ VALVOJ. Raporto de Parolado ĉe la Radio-Societo de Granda Britujo, de S-ro.—A. C. Bartlett.

La parolinto traktis ĉefe pri la interna funkcio de valvoj kaj pri kelkaj el la punktoj, kiuj prezentas sin je la desegnado de pligrandaj tipoj de valvoj.

Unue traktante pri la malgranda du-elektroda valvo, li diskutis la faktorojn, kiuj regas la anodan kurenton, uzante proksimuman matematikan traktadon ŝuldatan al Langmuir. Poste li diskutis la desegnadon de valvoj cilindroformaj, inkluzive je rektifikatoroj de la binokla tipo, kaj la efekton rezultintan kiam la filamento estas varmigita per alterna kurento. Li poste pritraktis la efekton de la proporcio $\frac{\text{Anoda Radio}}{\text{Katoda Radio}}$ montrante la avantaĝojn havigotajn per valvoj de la tipo kun sendepende varmigita katodo.

Fine li diskutis metodojn de regado de anoda kurento, ekzemple, magneta regado, kaj la ordinara metodo de krada regado.

Raporto pri la diskutado, kiu sekvis la paroladon, estas donita.

MEZUROJ KAJ NORMOJ.

PLIBONIGAĴO DE LA " DUOBLA-KLAKETA " METODO MEZURI RESONANCAN ONDOLONGON.

Post diskutado pri la malavantaĝoj de la " duobla-klaketa " metodo, la aŭtoro sugestis la utiligon de kradrezistanca interuptora efekto, kiel montrita de F. M. Colebrook en *Wireless World*, 6a de Oktobro, 1926a. Se la krada kondensatoro de la ondometra interuptora cirkvito estas alĝustigita, tiel ke interupto estas *apenaŭ* kreita, la agordado pro resonanco de la provata cirkvito estingas la interupton super spaco kunrespondanta al la spaco inter la ordinarak klaketoj. Per nerigidigo de la kuplado, la larĝeco de ĉi tiu " silenta spaco " povas esti multe malpliigita, ĝis ĝi fariĝas nur ŝanĝo de kvalito kaj tono de la zumado.

LA ĜUSTA KAJ PRECIZA MEZURADO DE ONDOLONGO EN RADIO-SENDAJ STACIOJ.—R. Braillard & E. Divoire.

Daŭrigita el la antaŭa numero, de la Prezidanto kaj Sekretario de la Teknika Komisiono de la *Union Internationale de Radiophonie*.

La nuna parto daŭrigas la priskribon de la normiga ondometro por brodkastaj sendaj stacioj, traktante pri la indikatora cirkvito. La elektraj dimensioj de ĉi tiu cirkvito estas diskutitaj, aparte rilate al komuna indukteco kaj la permesebla resisteco.

La aŭtoroj poste priskribas la metodon de normigado. Multavibratoro estas uzita, funkciigita de valvsubtenita forko, harmonikoj estante elektitaj laŭordinare. Aldona heterodina oscilatoro povas esti uzita por eĉ plialtaj frekvencoj. La normigaj

cirkvitoj estas ilustritaj, kaj la antaŭzorgoj necesaj je la funkciado estas pritraktitaj. Fine la aŭtoroj diskutas la diversajn faktorojn, kiuj tuŝas ondometran normigadon kaj korektecon.

HELPA APARATO KAJ MATERIALOJ.

NOVA TIPO DE LAŬTPAROLILO.

Redakcia noto pri nova tipo de kondensatora laŭtparolilo, ŝuldata al D-ro. G. Green, de Glasgow.

DIVERSAĴOJ.

RESUMOJ KAJ ALUDOJ.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

LABOREJO DE SENFADENA FABRIKEJO. Resumo de prelego legita de S-ro. P. K. Turner, A.M.I.E.E., ĉe la Senfadena Sekcio de la Institucio de Elektraj Inĝenieroj, Londono, je 18a Majo 1927a.

La prelego priskribas la ekipajaron de la Laborejo de la Esplora Fako de Burndept Wireless Ltd., Londono.

La afero estas dividita laŭ la rubrikoj, Funkcioj Lokigo kaj ĝeneralaj Aranĝoj, Kontinukurenta Laborado (inkluzive je bateria provizado, mezuraj instrumentoj kaj normiloj, rezistiloj, kondensatoraj provoj, k.t.p.), Proviza Frekvenca Laborado, Aŭdfrekvenca Laborado (inkluzive je Malalt-frekvenca fonto laŭ la heterodina principo, valva voltmetro, kombinita Alternkurenta kaj Kontinukurenta Ponto, k.t.p.), Radio-Frekvenca Laborado (inkluzive je mezurado de frekvenco, kapacito kaj indukteco, altfrekvenca rezisteco, k.t.p.).

La resumo estas ilustrita per diagranoj kaj fotografaĵoj, plispeciale de la valvprova aparato, aŭdfrekvenca fonto, kombinita A.K. kaj K.K. Ponto, k.t.p.

Raporto pri la diskutado, kiu sekvis la legadon de la prelego estas ankaŭ donita.

MATEMATIKO POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto traktas pri la operatoro "j," la operatoro $(a+jb)$, adicio de operatoroj, egaleco de operatoroj, multipliko de operatoroj, alternativa formo por $(a+jb)$, adicia formularo de trigonometro, la eksponenta formo por (kosinuso $\theta + j$ sinuso θ) seria formo por sinuso kaj kosinuso, radiokoj de operatoroj, k.t.p.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

Slope Inductance.

To the Editor, E.W. & W.E.

SIR,—The subject raised by Mr. C. R. Cosens in your issue for June is one which has interested me for some time, as the behaviour of iron-core inductances in valve circuits is, as he points out, vastly different from that in, say, power transformers. Its investigation is, however, beset with many pitfalls, and I submit that some of these have not been avoided by the treatment in question.

The method which I have found most satisfactory for measuring inductances in the presence of polarising current is similar to that described by Mr. Cosens, but with this important difference, that in addition to the voltmeter readings across the impedance to be measured and across the non-reactive rheostat, a third reading is taken across both in series. It is then possible to deduce the effective A.C. resistance of the impedance, which is information quite as valuable as that concerning the inductance. Results obtained by this method showed that the usual assumptions regarding A.C. resistance were quite erroneous, as pointed out in my letter on the subject in your issue of September, 1926. A number of most interesting facts have thus been brought to light, such as the variation of A.C. resistance with amplitude of A.C. and D.C., the effects of various numbers of shorted turns and of resonance, the motional loads of loud-speakers, etc., into which it is impossible to enter in a brief space: but it may be stated shortly that even the assumption that the A.C. resistance is double the D.C. resistance is justifiable in only a very few cases of practical importance. Even at low commercial frequencies the A.C. resistance of, say, an amplifying transformer winding may exceed 15 times the D.C. resistance.

In the analysis given, Z is referred to as the impedance of the choke: it would appear, however, from Mr. Cosens' equation (1) that Z is the impedance of both choke and rheostat in series, though there is no indication that this quantity is actually measured, mention being made only of measurements across the two components separately.

It is rather difficult to see why, in Fig. 2, a complicated arrangement of chokes and condensers is shown in order to separate the D.C. and A.C. supplies. Personally, I have found it much simpler to run them both in series. I should like, also, to ask why the battery and milliammeter should be damaged by superimposing an A.C. ripple of amplitude less than the D.C.; it is a common enough condition in radio work. The reading of the D.C. meter is not affected by the ripple, as a simple integration will show, provided that a moving coil instrument is used.

The suggestion that in the case of a transformer test the D.C. should be applied to the other winding is one that would naturally be made; but on consideration it will be seen that in order to maintain a D.C. supply it is necessary to have a closed circuit

and neither the inductance nor the resistance of the transformer measured in this condition will be even approximately the same as if measured otherwise.

It has been found that a slide-back voltmeter is superior to the Moullin type, as the range of the former is unlimited, whereas there are difficulties with the latter when the potentials to be measured are greater than 10 volts: the grid Moullin in particular is inadvisable owing to its load, which is sufficient to cause considerable error in practical cases. A slide-back voltmeter with grid condenser appears to be less liable to error than any other type when correctly applied, and no difficulty has been experienced in getting cheap paper condensers of 0.25μF with an insulation resistance of over 10,000 megohms. The frequency and leakage errors can be calculated, and are utterly negligible.

In describing the connections of the Moullin voltmeter, Mr. Cosens advises that the filament should be permanently connected to the junction of the choke and rheostat. This means that opposite halves of the A.C. are connected to the grid in turn in taking the two readings: error has been traced to this practice, since it is not possible to assume that the wave form of the supply mains is symmetrical about the zero line, and valve voltmeters are sensible to variations in peak value. It is therefore safer always to rectify the same half cycle.

I agree in principle with Mr. Cosens' recommendation to measure one thing at a time, but is it not desirable to make sure that the right thing is selected? It is, in my opinion, less interesting to know the true inductance of a coil, neglecting such effects as the self-capacity of the windings, than to know the apparent inductance, which includes all effects present when the coil is actually in use. A statement of apparent inductance and resistance at all working frequencies is, it is true, a confession of ignorance as to the exact composition of these fictitious quantities, but it nevertheless gives the information which can be applied in practical design: a neglect of any of the factors involved lowers the value of the statement greatly.

MARCUS G. SCROGGIE.

The Audio-Transformer Problem.

To the Editor, E.W. & W.E.

SIR,—I was pleased to find, on opening my June number of *E.W. & W.E.*, a contributory letter on this subject from Mr. P. K. Turner. On perusal of this, however, I cannot clearly gather what factors of the problem he considers I have neglected, and regret the absence of a clear statement to that effect.

On various points in the letter may I make a few minor criticisms?

Why introduce (as the "simplest form"!) the relatively complicated mathematical procedure leading up to the simple equation (7) which could have been written down at once from first principles? It appears to me liable to confuse those of us who could otherwise follow the remainder quite well.

Are not equations (2) only approximations *after* s^2X_1 has been neglected in comparison with Z_3? Surely the correct equations on the initially made assumptions, viz.:—

1. No leakage,
2. No secondary resistance,
3. No core losses,

are

$$R' = R_1 + \frac{s^2X_1^2}{R_3^2 + (s^2X_1 + X_3)^2} \cdot R_3$$

$$X' = X_1 - \frac{s^2X_1^2}{R_3^2 + (s^2X_1 + X_3)^2}(s^2X_1 + X_3)$$

though admittedly this correction does not affect Mr. Turner's procedure.

Now, passing over a considerable portion of the letter, Mr. Turner says, ". . . L_1 will be as large as we can make it" and "L_1 will probably be limited simply by the wire that can be got on." With these statements I do not in general agree, though, of course, it all depends upon what is meant by "as large as we can make it" and upon the dimensions of the transformer core and the amount of space allotted to the primary winding. My reasons for non-agreement have been given in my letter which you have published in your July issue. As pointed out earlier in Mr. Turner's letter, we do make the secondary inductance (in a given winding space) as high as we can. It would, however, defeat the purpose of a transformer to make the primary of equally high inductance.

I maintain that a first-class stage transformer will be such that its primary winding is *not* of the highest inductance possible in the space occupied by it, even when intended for use with a valve of usual impedance, and certainly when intended for use with a valve of low impedance.

In my last letter I gave reasons for the use of *high* primary inductance. May I now be permitted to cite one or two reasons against making this primary inductance unduly high? They are:—

1. Loss of general amplification as a result of a lowering of the turns ratio.
2. The maintenance of uniformity of amplification of the high frequencies with those of medium register is impaired by the increase of the effective primary capacity equivalent of that of the secondary.
3. Increasing initial magnetising effect of steady plate current of valve.
4. The increased possibility of self-oscillation of the andio-frequency amplifying train.

E. FOWLER CLARK.

New Developments in Resistance Amplification.

To the Editor, E.W. & W.E.

SIR,—The interesting article by Mr. Colebrook on Resistance Amplification in the April issue of *E.W. & W.E.* appears to be misleading in one place. In discussing multi-stage amplifiers Mr. Colebrook states that the grid-leak resistance must be large compared with the internal slope resistance of the preceding valve and need not be large compared with its anode resistance. Surely this must be incorrect, because the grid-leak and anode resistance are in parallel and the two together in series with the internal slope resistance of the previous valve: if the grid-leak were zero the anode resistance would be short-circuited and the amplification would become zero. The formula for the

amplification has been reduced to a form which leads readily to misinterpretation and evidently this has been the cause of the misconception. We will assume the impedance of the coupling condenser is sensibly zero and then the network shown in Fig. 9 of Mr. Colebrook's article reduces to the grid-leak R_1 in parallel with the anode resistance R of the previous valve, these two together being in series with the internal slope resistance R_a. It then follows readily that the amplification factor m is given by the expression

$$m = \frac{R\ R_1}{R\ R_a + R_a\ R_1 + R\ R_1}\mu$$

This expression may be re-arranged in the form

$$m = \left(\frac{R_1}{R_1 + \dfrac{R\ R_a}{R + R_a}}\right)\left(\frac{R}{R + R_a}\right)\mu$$

$$= \left(\frac{R_1}{R_1 + R_0}\right)\left(\frac{R}{R + R_a}\right)\mu$$

and this is the expression given by Mr. Colebrook.

Now since $R \gg R_a \quad R_0 \doteqdot R_a$

$$\therefore \qquad m \doteqdot \left(\frac{R_1}{R_1 + R_a}\right)\left(\frac{R}{R + R_a}\right)\mu$$

This expression for m is the product of the amplification factors which would obtain if R and R_1 respectively were infinite. It is true that if $R_1 >> R_a$ and if $R >> R_a$ then the value of m tends to unity, but unless $R_1 >> R$ the first factor is the dominant term. Let us take the values used by Mr. Colebrook in his numerical example: viz., $R = 2\text{M}\Omega$, $R_1 = 5\text{ M}\Omega$, $R_a = 0.4\text{M}\Omega$. If R_1 is infinite then $m = 0.83\mu$, but if $R_1 = 5\text{ M}\Omega$ then $m = 0.78\mu$. Thus the 5 MΩ grid-leak has reduced the value of m by 6 per cent. If we make $R = 4\text{ M}\Omega$ vice 2 MΩ, then $m = 0.85\mu$, whereas if R_1 had been infinite then $m = 0.91$. Again if $R_1 = 20\text{ M}\Omega$, $R = 2\text{ M}\Omega$ and $R_a = 0.4\text{ M}\Omega$ then $m = 0.82\mu$. Hence I maintain that the grid-leak resistance must be many times the previous anode resistance if we are to obtain sensibly the full advantage of very high anode resistances. It is interesting to compare the values just found for m with the values we might readily obtain with moderate anode resistances and using the straight portion of the characteristic. For example, if $R_a = 20 \times 10^3\ \Omega$, $R = 100 \times 10^3\Omega$ and $R_1 = 0.5\text{ M}\Omega$, then $m = 0.81\mu$: a value which is 4 per cent. higher than that contemplated in Mr. Colebrook's example with an anode resistance of 2 MΩ. Therefore it seems that practical limitations of the grid-leak resistance will obliterate the gain which otherwise could result from the use of a very high anode resistance. Thus it seems that the system of using very high anode resistances has the advantage only of permitting a smaller filament current and a possible slight reduction of high tension voltage. We must be prepared to pay for this small advantage by some small additional distortion and very great additional care in the insulation of component parts.

E. B. Moullin.

Cambridge.
21st June, 1927.

Some Recent Patents.

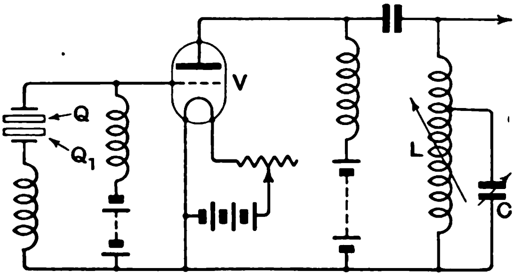
The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

PIEZO CRYSTAL CONTROL.

(*Convention date* (*U.S.A.*), *2nd October*, 1925. *No.* 259,174.)

In this patent, Wired Radio Inc., an American Corporation, cover the simultaneous application of a number of piezo crystals, of different fundamental frequencies, to a circuit which allows any one of the crystals to be selected at will to determine the output frequency. As shown in the figure a stack of crystals Q, Q_1, ground to different frequencies, are mounted between a pair of metallic electrodes, shunted across the grid and filament of the valve V.

The method of selection depends solely upon the tuning of the plate circuit L, C. It is found that each of the crystals Q, Q_1 will function independently of the others, so that a stabilised output can be maintained, at the fundamental frequency of any selected crystal, merely by tuning the plate circuit to that frequency. It is not desirable to use a stack of crystals separated too far apart in



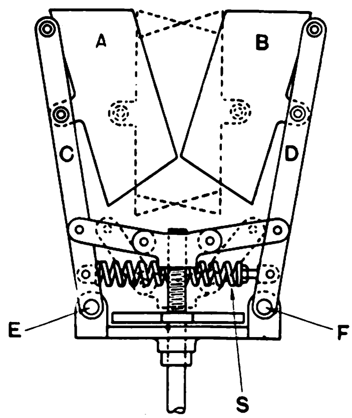
fundamental frequency, but satisfactory results have been secured in shifting the stabilised output from 3,300 to 4,000 kilocycles, that is, over a belt of 700 kilocycles. The arrangement can be used for heterodyne reception or for controlling the output of a transmitting station at any one of a number of different frequencies.

LATERAL-MOTION CONDENSERS.

(*Application date*, *10th February*, 1926. *No.* 270,020.)

It is a characteristic of the straight-line frequency type of condenser that as the capacity in circuit increases so should the rate of overlap of the condenser plates increase for equal angular movements of the control knob. This result is secured in Mr. T. S. Riley's patent by mounting the pairs of co-acting plates A, B on two converging arms C, D, pivoted to the frame at E and F. Relative movement of the plates is secured by means of a slider carrying a pair of links connected to the arms C, D.

As the slider is moved downwards along a screw-threaded spindle, the plates move inwards towards full engagement against the pressure of a spring S. Owing to the toggle-joint arrangement of the arms and links, the rate of overlap is gradually accelerated for successive equal movements of the slider or,

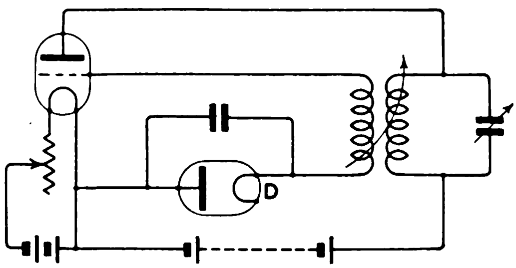


in other words, for equal angular displacements of the condenser control knob. Pinion gearing is provided for fine tuning.

POWER OSCILLATORS.

(*Application date*, *6th May*, 1926. *No.* 270,488.)

The danger of a sudden reversal of grid current, owing to secondary emission from the grid momentarily exceeding the primary emission, is prevented according to this patent of the N. V. Philips Gloeilamp Co. by inserting an auxiliary diode tube in the grid circuit as shown. The one-way conductivity of the diode ensures the correct polarity

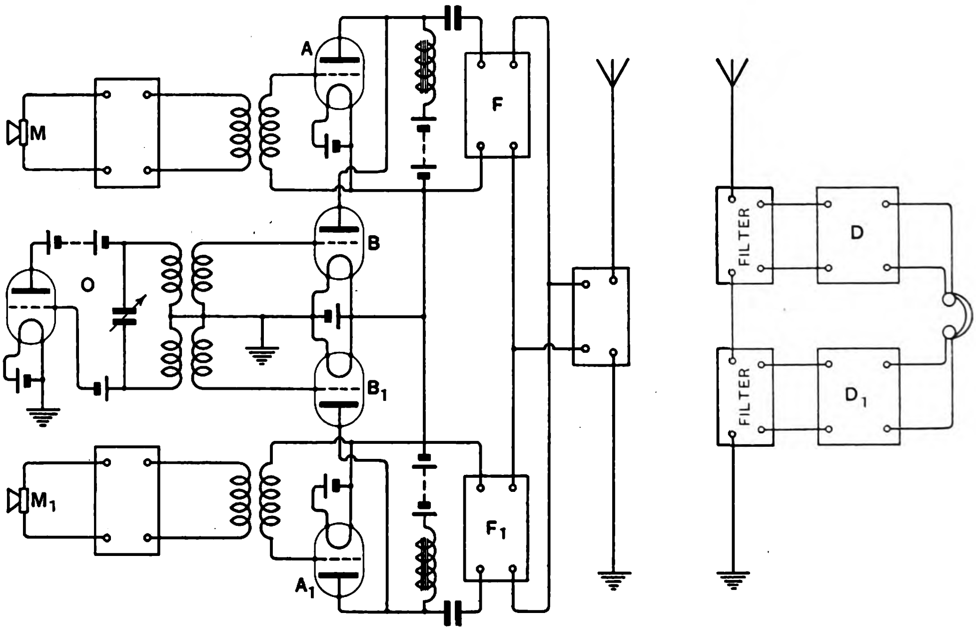


of the grid current, and thus acts as a safeguard against possible damage. In the same way any excessive potential difference between the grid and plate, which might lead to puncturing, is relieved by shunting a safety diode valve directly across the terminals in question.

STEREOPHONIC BROADCAST.

(*Application date, 2nd February,* 1926. *No.* 270,001.)

So-called "plastic" or stereophonic effects in broadcast reception have been secured by radiating simultaneously two carrier-waves of different wavelengths, these carrying the modulation from two separate microphones so as to maintain the phase-difference necessary to ensure a true binaural effect. The Standard Telephones & Cables, Ltd., propose to simplify this procedure by making use of only one carrier, and diverting the upper and lower sideband frequencies into separate channels.



As shown in the figure a valve generator O supplies the carrier frequency to modulators B, B_1. The low-frequency signals are supplied through amplifiers A, A_1 from two microphones spaced sufficiently apart to impart the required phase-displacement. The output from the modulator will contain sum and difference frequencies, which are kept separated by two filters F and F_1, the former passing the higher sideband and the latter the lower sideband. In addition there is sufficient overlap between the cut-off characteristics of the filters to pass a proportion of the original carrier frequency.

The radiated energy will therefore contain two versions of the original sound, although the wave as a whole will occupy only the same width as a single broadcasting channel, a point of outstanding importance in the present state of ether congestion. Moreover, as only one aerial and one amplification system and power supply are required, the cost of initial equipment and upkeep is materially reduced.

At the receiving end, Fig. 2, the signals are passed first through two filters similar to F and F_1 of Fig. 1, and then through two separate detectors D, D_1, the final output being led to the individual earpieces of a pair of telephones or to two separate loud-speakers.

LIGHT-SENSITIVE CELLS.

(*Application date, 21st October,* 1925. *No.* 270,222.)

In order to minimise the time-lag effect of light-sensitive devices used in television systems, Mr. J. L. Baird proposes to use the "first differential" of the initial cell response, either alone or in combination with the normal primary response.

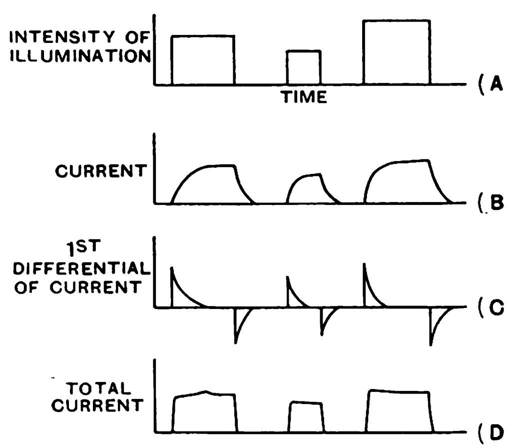


Fig. *A* shows, on a time basis, the intensity of illumination applied in the first instance to the sensitive cell. *B* is the corresponding "response" current from the cell. If this current is passed through the primary winding of a transformer, the induced current (or "first differential") in the secondary winding will have the form shown in graph *C*. For impulses of very short duration, the form of *C* will approximate more closely to the original stimulus *A* than the form shown in *B*. By combining *B* and *C* together upon the modulator, or other device to be operated, the effective result is as shown in the graph *D*. The latter is nearer *A* in form, for light impulses of comparatively long duration, than either *B* or *C*.

SUPPLY FROM THE MAINS.

(*Convention date* (*U.S.A.*), *27th April*, 1925. *No.* 251,240.)

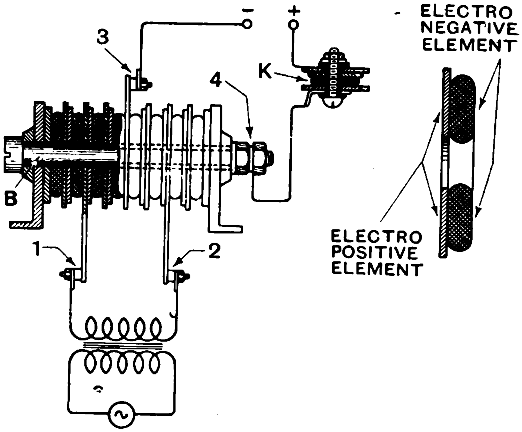
Both the plate and filament supply are taken directly from the house-supply mains through a battery of electrolytic cells *A*, *B*, *C*, *D* arranged to give full-wave rectification in the case of an A.C. supply. In the case of direct-current mains the supply leads can similarly be connected across the same terminals without danger of short-circuit. Each rectifying cell comprises an aluminium electrode and one of iron or lead immersed in an electrolyte of borax, sodium, or ammonium phosphate.

The filaments are fed in series through a resistance *R*, from which successive tappings are taken to the plates as shown. Parallel resistances r . . . . r_5 are shunted across each of the filaments, and are made of decreasing value to compensate for the fact that the anode current of each valve is added to the filament current of succeeding valves. Tappings are taken from the resistances r, r_1, etc., to furnish the operating grid potentials. A master rheostat is provided at r_6, whilst an additional resistance r_7 ensures a high negative resistance on the grid of the last amplifier.

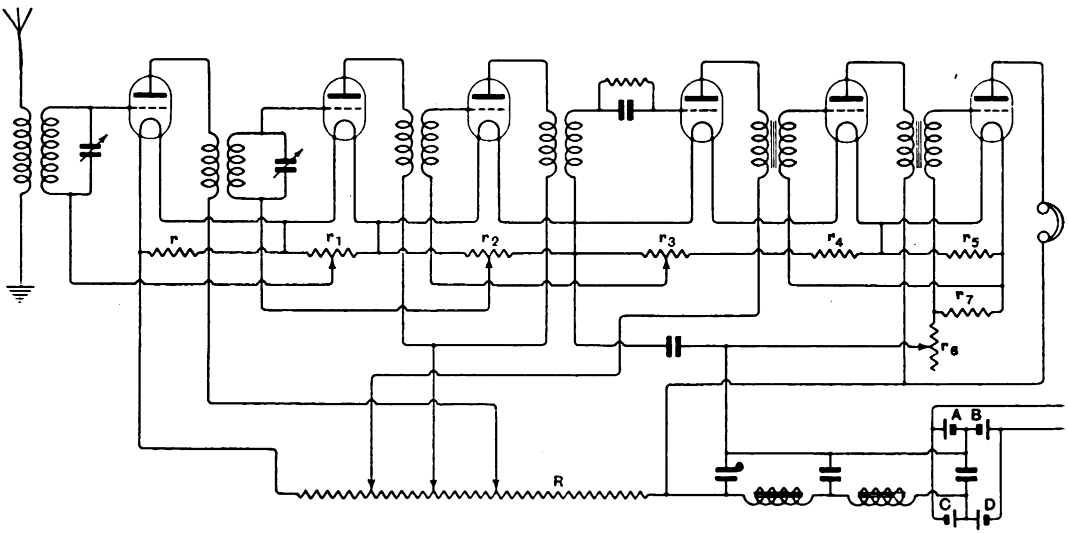
DRY SURFACE CONTACT RECTIFIERS.

(*Application date, 2nd December*, 1925. *No.* 270,362.)

A rectifying couple having inherent film-forming characteristics is described by Mr. Rubens, in which the electro-negative unit is made or compounded of metals of the sixth group in the Periodic table, whilst the positive element comprises one or more of the lighter metals of the second and third Periodic groups. More particularly the negative unit may be made of a mixture of 85 per cent. copper with 15 per cent. zinc, whilst the positive unit is preferably formed of copper combined or alloyed with silver, zinc, tin or antimony.



The elements are made in annular form, and are assembled in successive pairs on an insulated bolt *B*, the completed stack being maintained under lateral pressure. As employed for full-wave rectification, the input from the A.C. source is connected across the electrodes 1, 2, the rectified output appearing across the terminals 3, 4.



NEUTRALISING VALVE CAPACITIES.

(*Application date, 14th August,* 1926. *No.* 270,531.)

In this arrangement Mr. C. P. Allinson pushes the utility of the Wheatstone bridge as a radio-frequency stabiliser another step forward by including the internal plate-grid capacity as well as the grid-filament capacity in the balancing arms.

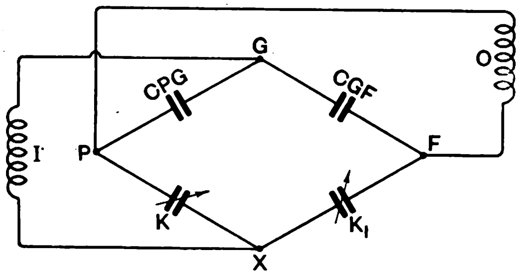


Fig. 1.

The schematic diagram of Fig. 1 shows the internal plate-grid capacity at *CPG*, whilst complementary grid-filament capacity is represented by *CGF*. Condensers K, K_1 of manageable size are included in the remaining arms and are adjusted to secure a correct balance.

The input coil 1 is connected from the grid G to a point X, which is separated from the filament F or earth potential by the condenser K_1. The plate or output coil occupies its usual position across plate and filament. Alternatively the input coil may connect grid and filament direct, in which case the output is branched from the plate to a point separated from the filament by the condenser K_1.

One circuit embodiment is shown in Fig. 2, the relation of which to Fig. 1 will be obvious from a study of the various reference letters. A high resistance R for stabilising the grid potential may be inserted across the condenser K_1, or in either of the positions shown in dotted lines. The balancing condensers K, K_1 may be replaced by equivalent inductances. Fig. 3 shows such an

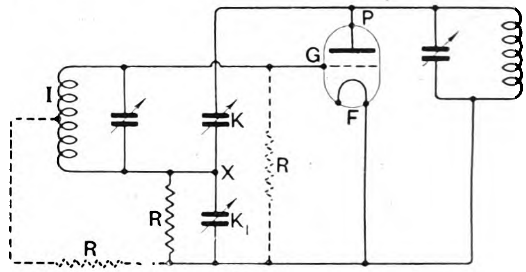


Fig. 2.

arrangement in which the two parts L, L' of the output coil on either side of the tapping point X

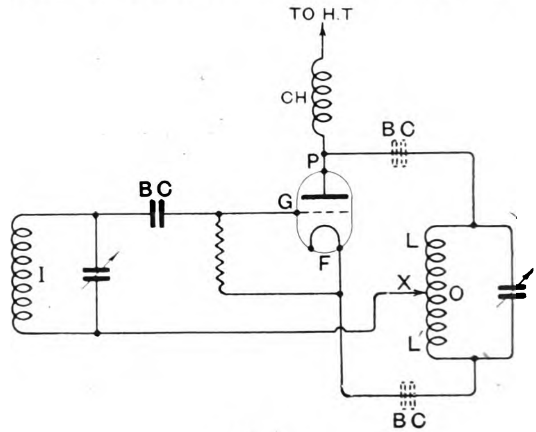


Fig. 3.

are made to serve this purpose. A blocking condenser *BC* may be inserted in any one of the positions shown.

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EXPERIMENTAL WIRELESS
& The WIRELESS ENGINEER

VOL. IV. SEPTEMBER, 1927. No. 48.

Editorial.

Short-wave Broadcasting.

A GREAT deal of attention is being focused at present on the subject of the application of short-wave transmission for the purpose of broadcasting from the home country to all parts of the Empire. The suggestion that an Empire broadcasting station should be established was, we believe, first put forward by our sister journal, *The Wireless World*, and the prominent position which the subject has taken in what we may describe as "broadcasting politics" is due to the persistence of that journal in advocating that a station should be established for this purpose.

The question which at first arose was naturally that of whose business it was to put up the transmitter, but the B.B.C. solved that difficulty for us by intimating that they had the project under way. In a letter to the *Times* recently the Chief Engineer of the B.B.C. has explained officially the policy of the Corporation on the subject, and from his letter it appears that the view adopted is that it is a matter to be undertaken only with the utmost caution and not to be essayed seriously until short-wave transmission and reception of broadcasting has developed to a stage approaching perfection. No doubt the Chief Engineer has some substantial reason (which he does not disclose) to justify this policy. For ourselves, we should think that short-wave broadcast transmission has reached a stage of development when the establishment of an Empire broadcasting station would not be premature. There is no doubt that a good deal of practical work remains to be carried out before anything like perfection of reception in remote parts of the Empire can be achieved, but we think that little will be done until a station is in operation as subject matter for the experiments.

We seem to recollect that in the early days of our broadcasting service in this country reception was by no means satisfactory, nor was the quality of the transmissions above suspicion. The broadcasting service is one which has developed gradually from an experimental stage. One hesitates to suggest it, but to be consistent in his policy our Chief Engineer would have preferred that we had waited, say, for the establishment of the regional scheme before any broadcasting was conducted here, rather than have begun with the Writtle experimental transmitter and its successors in the various stages of development.

High Frequency Resistance.

By A. G. Warren, M.Sc., M.I.E.E., F.Inst.P.

Inductance Coil in a High Frequency Circuit.

ALTHOUGH the quantities involved in high frequency work are usually the same as those of low frequency engineering, the differences of magnitude are so great that methods of measurement which are practicable in the latter case are often useless at radio frequencies. The difficulties encountered in high frequency measurement are mainly of two kinds: (1) that which has just been mentioned, viz., the inapplicability of methods which are capable of accuracy at low frequencies, and (2) what may be termed the "impurity" of the quantities to be measured.

Suppose we consider the second point first. Both the admittance of a condenser and the reactance of an inductance are proportional to the frequency. Capacities and inductances, therefore, whose magnitudes are negligible at ordinary frequencies, may become very important at high frequencies. This is a point to be noted by itself; but the point to be considered at the present moment is that a piece of apparatus often possesses, in a very marked degree, properties which it is not desired to possess. For low frequencies one may construct a resistance in which the effects of any associated inductance or capacity are negligible, or an inductance in which any capacity effects may be neglected. Although the property which the piece of apparatus is desired to have is always adulterated to a certain extent, the effects of such adulteration may be insignificant. As, however, the frequency increases this ceases to be the case and the effect of adulteration at high frequency may be so considerable that even definition becomes a matter of some doubt. Particularly is this the case when the applied frequency first approximates to, and then exceeds, the natural frequency of the piece of apparatus considered.

For example, let us consider an inductance coil. The turns of the coil possess capacity with respect to one another. At high frequencies part of the current entering a section of the coil, instead of traversing the conductor, proceeds as a displacement current. This is, of course, a distributed process, the total displacement current increasing as the centre of the coil is approached. This shunting effect does not reduce the current at the centre of the coil, as might appear at first sight, because the conduction current and the displacement current are almost opposite in phase. For frequencies below the natural frequency of the coil the current is a maximum at the centre and a minimum at the ends. Above the natural frequency of the coil the problem is more complicated and will be considered later.

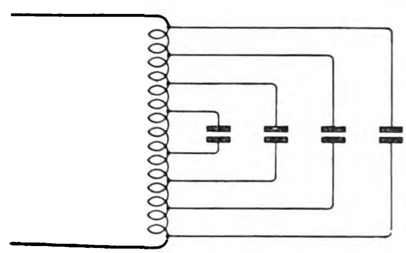


Fig. 1. *Condensers representing the self capacity of an inductance coil.*

The actual state of affairs could be represented somewhat as Fig. 1, where a large number of suitably chosen condensers are imagined shunting a coil which otherwise possesses no capacity. A rough idea of the behaviour of such a coil may be obtained by considering the circuit of Fig. 2. Here it is imagined that the actual coil may be replaced by an ideal inductance shunted by a single condenser. Such an approximation has been used by various writers (*e.g.*, Lindemann). Suppose it is possible to measure the current I flowing into the coil, the potential E across it, and the power P dissipated in it. Let I_L and I_C be respectively the inductive and capacitative components of I. The true resistance R of the coil is given by

$$R = P/I_L^2 \quad \ldots \quad \ldots \quad (1)$$

its apparent resistance from instrument readings is

$$R' = P/I^2 \quad \dots \quad \dots \quad (2)$$

whence

$$R/R' = (I/I_L)^2 \quad \dots \quad \dots \quad (3)$$

We have

$$E = (R + j\omega L)I_L \quad \dots \quad \dots \quad (4)$$

and

$$I_C = j\omega CE \quad \dots \quad \dots \quad (5)$$

whence

$$\begin{aligned} I &= I_L + I_C \\ &= E(1 - \omega^2 LC + j\omega CR)/(R + j\omega L) \quad (6) \end{aligned}$$

and

$$I/I_L = 1 - \omega^2 LC + j\omega CR \quad \dots \quad (7)$$

It is only the numerical value of this expression which is of importance. In most cases R is negligible in comparison with ωL and so except at or very near resonance (where $1-\omega^2 LC=0$), $j\omega CR$ may be neglected and

$$R/R' = (1 - \omega^2 LC)^2 \quad \dots \quad (8)$$

At resonance

$$R/R' = \omega^2 C^2 R^2 = R^2/\omega^2 L^2 \quad \dots \quad (9)$$

Very near resonance the expression (7) must be evaluated more exactly.

The above expressions may be illustrated by considering a coil of inductance 1mH having a capacity of $25.3\mu\mu$F. We cannot define its resistance, as that changes rapidly with the frequency, but we shall assume it small compared with ωL. We may, however, examine the effect of resistance by assuming that at about 10^6 cycles, which is the resonant frequency of this coil, its resistance is 2 ohms. The following table is self-explanatory. It is seen that for the tabulated values the expression $j\omega CR$ is negligible except at the resonant frequency.

It will be seen that reasonable values for the resistance are obtained from equation (2), $R = P/I^2$, so long as the frequency is less than one-tenth of the resonant frequency of the coil. Above this, calculations from equation (2) give values increasingly too great until resonance is attained. Above resonance, values calculated from this expression are at first too great and later too small. No reliance can be placed on calculations from such instrument readings except below one-tenth of the resonant frequency.

TABLE I.

f	I/I_L	R/R'
0.1×10^6	0.99	0.980
0.5×10^6	0.75	0.562
0.8×10^6	0.36	0.130
0.9×10^6	$0.19 + .0003j$	0.036
10^6	$0 + .000318j$	10^{-7} approx.
1.1×10^6	$0.21 + .00035j$	0.044
1.2×10^6	0.44	0.194
1.3×10^6	0.69	0.476
1.4×10^6	0.96	0.922
1.5×10^6	1.25	1.562

Effect of Distributed Capacity of an Inductance Coil.

The circuit of Fig. 2 is only a very rough approximation and is not capable of affording reliable information when the frequency approaches or exceeds the natural frequency of the coil. If we consider the condensers shown in Fig. 1 to be representative of a large number of condensers of the correct magnitude, at least a qualitative insight into the behaviour of the coil can be obtained.

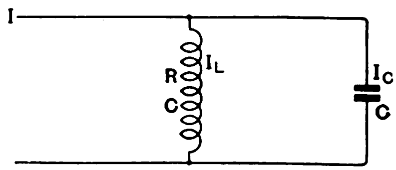


Fig. 2. *Rough approximation to self capacity of inductance coil.*

More than that will not be attempted at present. The exact solution of the problem is one of great difficulty and as far as the writer is aware has not been completely worked out. Here we shall only attempt to obtain an approximate idea of the current changes down the coil. For simplicity one may assume either (*a*) that condensers of suitable magnitudes are connected at equal intervals down the coil or (*b*) that a number of equal condensers are connected at suitable points, or what would offer greater difficulties from a quantitative point of view but is simpler in our case; or (*c*) that condensers are connected of such magnitudes and so disposed that they take equal currents (Fig. 3).

For frequencies below resonant frequency the current I_0 taken by the coil lags behind the voltage by practically 90 degrees (Fig. 4) the current $I_1 = I_0 - i_1$ and since i_1 leads the voltage by 90 degrees, I_1 is equal to the

numerical sum of I_0 and i_1. Similarly $I_2 = I_1 - i_2$, etc. Fig. 4 shows how the magnitude of the current grows towards the centre of the coil.

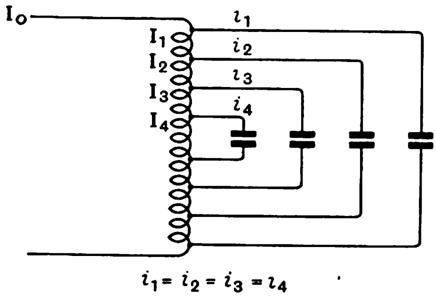


Fig. 3. *Imaginary condensers so disposed that they take equal currents.*

When the frequency exceeds that of the coil the case is very different. The current I_0 then leads the voltage by practically 90 degrees. (This is only true when the frequency does not exceed that of the coil by too great an amount. As the frequency is increased the phase of the current undergoes successive reversals. This point is

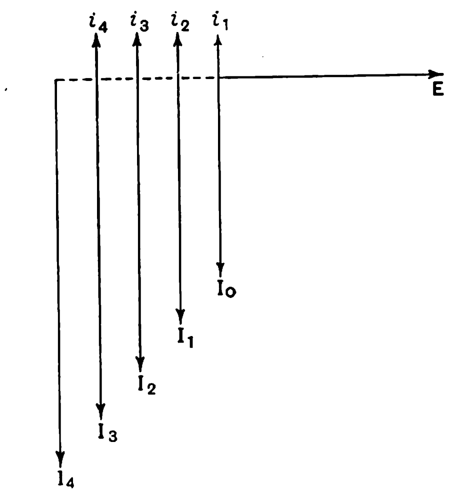


Fig. 4. *Vector diagram for circuit of Fig. 3.*

treated more fully later.) At some point down the coil there is a node of current beyond which the direction of flow is reversed. From this point the current grows until the antinode is reached, which may be at the centre of the coil. In the case of very long coils it is possible that there may be several nodes and antinodes at high frequencies. In any case, so long as the coil is symmetrical, and symmetrically disposed, an antinode of current will be at its mid-point. The current relations in a coil of moderate length are illustrated in Figs. 5 and 6.

It might now appear that the representation of the capacity of the coil by condensers distributed as in Figs. 3 and 5 does not indicate the true state of affairs. On very long coils some of the condensers will have voltages of opposite signs to others. A moment's reflection, however, shows that the representation is still correct: there are standing voltage and current waves upon the coil. The components i always lead the voltage by 90 degrees; this voltage varies in magnitude, and may be in the same

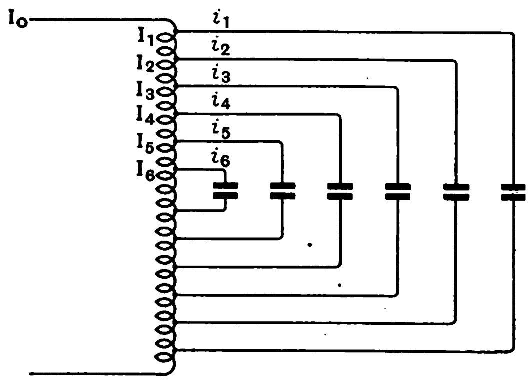


Fig. 5. *Approximate circuit assumed for a long coil at high frequency.*

direction or in the opposite direction to the voltage across the terminals of the coil. It would appear natural on very long coils to imagine the condensers connected to points equidistant from the antinodes of voltage of the same wave, such as AA'; no difference, however, occurs if they are imagined connected to points such as BB' which are at the same potential (Fig. 7). In the case of a short coil forming part of a tuned circuit oscillating at fundamental frequency, only part of a wave is situated upon the coil and the relations are as indicated in Fig. 8, the current being a maximum at the centre.

Resistance of an Inductance Coil.

At reasonably low frequencies there is no difficulty in defining with practical accuracy

what is meant by the resistance of the coil. The current has approximately the same value at all parts and, leaving out of consideration any losses in the dielectric or losses due to radiation from the coil, the resistance may be defined as the power divided by the square of the current. If

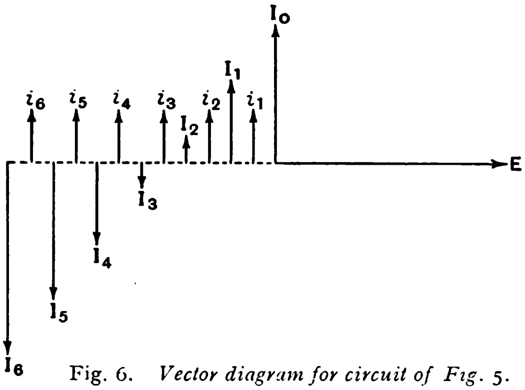


Fig. 6. *Vector diagram for circuit of Fig. 5.*

the power *dissipated* is measured, no error occurs due to any radiation which may take place. When, however, there are considerable differences in the value of the current at various parts of the coil the quantity given by the power divided by the square of the current at the *end* of the coil can hardly be said to be the resistance. If the current could be measured at all parts the resistance might be defined as the integral of dP/I^2 throughout the coil.

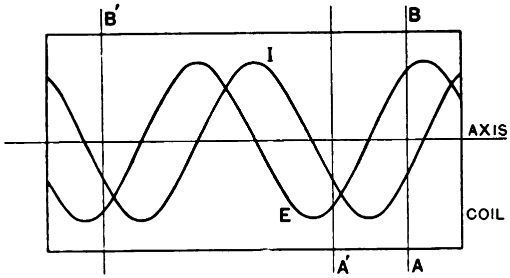


Fig. 7. *Showing distribution of current and voltage on a very long coil.*

From a scientific point of view the quotient, power/(input current)², is far too indefinite. If we take an extreme case, when the frequency is equal to that at which the coil will resonate, we have loss of power with practically no current, suggesting a nearly infinite resistance. This nearly infinite apparent resistance may be actually reduced by an increase of true resistance, or it may be actually reduced by an increase of true resistance, or it may be reduced by an increase in the length. (See equation (7) and Table I.) But such cases are rarely practical. Turning to actual practice we find that the problem with which the engineer is faced is this: Given a particular piece of apparatus what will its characteristics be at various frequencies? When the current in the circuit of which it forms a part is known in magnitude and frequency, what effective inductance and capacity has the apparatus, and what losses occur in it? If reduction

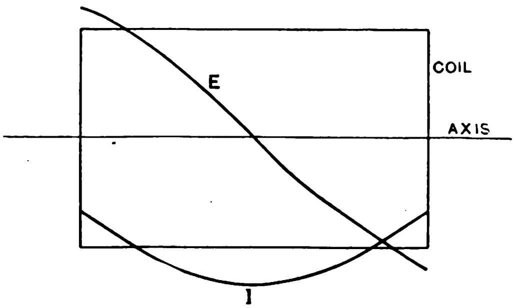


Fig. 8. *Current and voltage distribution on a short coil forming part of a tuned circuit.*

of loss is desirable, what is the distribution of the losses and how can such reduction be best effected? Towards the solution of such problems, a knowledge of the apparent resistance, as defined by the power divided by the square of the input current, offers one factor involved in the solution. So long as the frequency is reasonably lower than the resonant frequency, the apparent resistance does not differ greatly from the true resistance.

Effect of High Frequency Currents upon Resistance.

At high frequencies, as is well known, the current does not distribute itself uniformly over the cross-section of the conductor. In the case of a long straight wire the eddy currents caused by the flux within the conductor force the current towards the surface. The effect naturally increases with the frequency, until the current is practically confined to a thin surface layer. Another

way of looking at the same effect (due to Howe)* is to consider the transmission of energy into the conductor from the surrounding dielectric. This transmission is governed by the same laws as the main transmission along the conductor. It is of a wave nature, the wavelength decreasing with the frequency. At low frequencies the current changes in phase and attenuates as the centre of the wire is approached, so that the total current is considerably less than it would be if it had the same density everywhere as it has at the surface. At higher frequencies the attenuation becomes greater, and the wavelength less, so that at a short distance within the conductor there may be a small reverse current flowing. The effect of a non-uniform distribution of current is clearly to increase the effective resistance, since the loss at every point is proportional

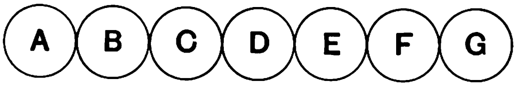


Fig. 9. *Parallel straight wires carrying equal currents.*

to the square of the current density. At high frequencies it is possible to reduce the effective resistance by making the wire hollow and eliminating the possibility of reverse current.

The case of a coil is much more complicated than that of a straight wire. The energy, instead of being propagated symmetrically into the conductor from all directions, is, for a conductor near the centre of the coil, propagated in the direction of the radius of the coil. The current is, in a single layer coil at high frequencies, confined almost entirely to a thin skin on the inside surface of the cylinder, there being practically no current at the outer surface. In general the coil resistance at a given frequency is considerably greater than the resistance of the wire of which it is composed, were the wire straightened out.

Notable contributions to an analytical solution of the problem have been made by Howe, who solved it for closely packed solenoids of square wire,† by Sommerfeld who obtained a solution for coils of large diameter of round wires in contact. In recent years the theory of the subject has been greatly developed by Butterworth. The reader is referred to his papers for a comprehensive analytical treatment of the subject.* Howe has assumed that the flux is parallel to the axis of the coil. This is true near the centre of long closely-packed solenoids, but it is far from true near the ends. The effect of obliquity of the field can be understood best by considering the eddy currents in any particular turn due to adjacent turns. We shall assume that the coil is being operated, as it most commonly is, at a frequency well below resonance, when we may assume with reasonable accuracy that the current is the same at all parts. Then the eddy currents produced in any particular conductor are due to the electromotive forces generated in it by the variation of its own internal flux and the variation of flux through it due to adjacent conductors. As a first approximation we may consider a number of parallel straight wires (Fig. 9). It is clear that the fields in *D* due to *C* and *E* largely cancel one another out, similarly the fields due to *B* and *F* and to *A* and *G*. If we consider the conductor *B*, the field due to the other conductors, at the instant when the current is flowing into the paper, is preponderatingly upwards. Still more is this the case for conductor *A*. One would therefore infer that the eddy currents produced in the end conductors would be much in excess of those in conductors near the centre, resulting in a greater heating loss, or a higher resistance at the ends. This is confirmed by the writer's experiments, described later.†

We see, therefore, that the resistance losses in a coil would be expected to be different in different parts. So long as the current is approximately the same at all parts of the coil, the losses will be much greater in the end turns. This represents a real increase of resistance to currents of the particular frequency. It is conceivable, however, that as the resonant frequency is approached the

* *Proceedings, I.E.E.*, Vol. 54, p. 473.
† *Ibid.*, Vol. 58, p. 152.

* See *Phil. Trans. A.*, Vol. 222, p. 57. 1921, for coils of greater diameter than length. Also *Proc. Roy. Soc. A.*, Vol. 107, p. 693, 1925, for closely wound coils. An excellent summary of much of this work appeared in *E.W. & W.E.*, April and May, 1926.)

† These experiments were carried out in 1921 before Butterworth's analytical work was available.

losses may become greater at the centre of the coil, when the current there is much greater than at the ends. The preliminary experiments which the writer has made call for repetition upon coils of all practical types; measurements near the resonant frequency would be of particular interest.

Practical Methods of Measuring Resistance.

Most methods which have been employed for high frequency resistance measurement have been subjected to considerable criticism. With any method of substitution or addition of resistance to a circuit it is extremely difficult to ensure that the general conditions of oscillation are unaltered. One of the chief sources of error is the effect of stray capacities. Bridge methods with coils of low power factor offer great difficulties. It "is equivalent to trying to weigh milligrammes with a 2 or 3 lb. weight on each side of the scale."* At high frequency the current is controlled almost entirely by the reactance of the circuit. Strict balance between two circuits can only exist when both the reactances and resistances are equal. Practical balances may, however, often be obtained when the quantities are fairly different. The calorimetric method, in spite of all the experimental difficulties, is not open to similar criticism. If the current into the coil can be measured, and the heat produced in it determined, the effective resistance can be readily calculated. There is no question of adjusting a circuit to a point of doubtful resonance or of balancing the coil against another circuit which more or less perfectly imitates it.

It has to be admitted that most calorimetric methods do not allow of rapid measurement, also that they are not capable of giving good results in unskilled hands. Often many corrections have to be applied, though these corrections can be made with a fair degree of accuracy and, when the final results are obtained, one can assume their approximate accuracy with confidence.

Objection has been raised to the calorimetric method on the ground that "it necessitates the use of much larger currents than the coils are often required to carry in practice."† The writer has not found this a serious objection. In the experiments described later the low frequency current through a coil of No. 20 S.W.G. copper wire rarely exceeded 5 amps. (The high frequency current was, of course, less.) The rise of temperature was never more than 5°C. Yet no difficulties occurred owing to the quantities being too small to measure. In the writer's second method this criticism is still less applicable.

There are many ways of applying the calorimetric method. One may actually measure the heat produced in the coil, and then from its thermal constants determine the resistance. It is usually more convenient to measure the heat produced by, first, a high frequency current and then by a low frequency or direct current. The ratio of the quantities of heat produced in unit time per ampere* in the two cases is the ratio of the high and low frequency resistances.

Methods may also differ in the thermal quantity that is measured. It may be the actual quantity of heat generated in the coil or it may be the rise of temperature which takes place in a specified time. Usually it is the latter. Temperature rise is usually determined by means of a thermojunction, though this is not the only means available.

Errors in Calorimetric Measurements.

The chief source of error in calorimetric measurements is the loss of heat from the conductor in which the heat is generated. A short time after the current is switched on we have copper, insulating covering, former and the surrounding air all at very different temperatures. Could these conditions be exactly reproduced on all occasions the calculated results at high and low frequencies would be strictly comparable and the determined ratio of the resistances at different frequencies would be correct. Unless very special precautions are taken, however, the repetition of circumstances cannot be assured. One day the cotton covering may be perfectly dry and the heat consequently retained much better by the copper than when the covering is damp. Dielectric losses occur in the covering and in the former.

* Fortescue, *Proceedings, I.E.E.*, Vol. 58, p. 163.
† Coursey, *Proceedings, I.E.E.*, Vol. 58, p. 164.

* Some objection may be taken to this expression; it is convenient, however; by it is meant the heat produced divided by the square of the current.

These tend to mask the resistance measurements and also result in the production of an amount of heat which may not be exactly reproducible even with currents of the same magnitude and frequency. Again, at fairly high frequencies, heat is generated at a greater rate at the ends of the coil than at the centre, whereas at low frequencies the heat is generated uniformly throughout the coil. It is hardly justifiable to assume that, when the same total quantities of heat are generated at high and low frequencies, the loss of heat is the same. In Howe's experiments the thermojunctions were situated near the centre of the coil and were only connected after the alternating current had been switched off. By this method errors due to capacity currents flowing along the thermojunction wires were obviated, but allowance was not made for the variation of temperature throughout the coil. In general, temperature measurements made upon a coil after a high frequency current has been passed through it for a definite time show that the heating is a maximum at the ends. Thermal conduction, however, tends to equalise the temperatures throughout the coil, and an estimation of the relative resistances of the various parts offers considerable difficulties.

At any instant the rate of rise of temperature of a conductor is determined by its thermal constants and the difference between the rate of heat generation in it and the rate at which heat is being lost. The rate of heat generation, which it is desired to measure, is thus the sum of two terms: (A) The *net* rate at which heat is being added; and (B) the rate of loss of heat. The second term is approximately proportional to the rise of temperature and is zero at the instant of switching on the current. It is, however, a somewhat variable quantity, even under apparently similar circumstances. Experiments of the writer show that the rate of loss of heat from a coil cannot be estimated with reasonable accuracy from the rate at which the coil cools after the current is switched off. The distribution of temperature during heating is very different to its distribution when cooling. In the first case heat is being given both to the surrounding air and to the former upon which the coil is wound. During cooling, heat is being received from the former at the same time as it is being lost to the air. One would expect, therefore, that the rate of loss of heat during cooling would be less than it is at the same temperature when heating. Experiment shows that it is actually less during cooling. Great reliance, therefore, cannot be placed upon calculations involving an estimate of the heat loss when that loss is comparable with the rate at which heat is generated.

Writer's Method of Determining Coil Resistance.

The distinguishing features of the method described below are :—

1. The *initial* rate of rise of temperature of different parts of the coil was measured, enabling

2. (A) The effects of variations of external thermal conditions upon different occasions to be eliminated;

(B) The resistance of different parts of the coil to be determined.

Thermojunctions of very fine wire were soldered to various parts of the copper of which the coil under test was made. The initial rate of heating of these junctions was determined, by a method to be described later.

The initial rate of heating is dependent only upon the rate of heat generation. Loss of heat and thermal conduction between different parts of the coil are not appreciable until there are sensible differences of temperature between the various parts of the coil and between the coil and its surroundings. The rate at which the temperature of the part of the coil under observation changes immediately after switching on the current is therefore a true measure of the rate at which heat is being generated at the point in question. The chief feature of the method, however, is not that it reduces the errors incident to the estimation of the cooling loss, but that it permits of point measurements of resistance being made. The true resistance loss in the copper is determined apart from losses in the former and surroundings.

Test Coil and Junctions.

The coil tested consisted of 119 turns of No. 20 S.W.G. D.C.C. copper wire, wound upon a paper tube, the mean diameter of

the coil being 10.8 cms.; and its length 15.7 cms. Its low frequency resistance was about 1.04 ohms. Its inductance, calculated from Lorenz's formula, was 0.792 millihenries.

The coil was placed in the dummy aerial circuit of a $\frac{1}{2}$kW Marconi valve transmitting set, capable of giving a high frequency current of 6 amps. High frequency currents greater than 3 amps, however, were rarely used. The coil was kept well removed from the generating plant. In fact, the two were in separate rooms, two pairs of leads connecting them—one in the high voltage circuit, the other in the grid-leak circuit. Adjustments were first made with the transmitting key closed, another coil exactly similar to the test coil being inserted in place of the latter. The transmitting key was then released and the test coil replaced. The junctions consisted of fine wires (2 mils.) of Eureka and platinum silver, soldered on to the bare copper. These wires in turn were soldered to No. 36 S.W.G. copper wires for connection to the junction terminals, the latter being carried upon a thin strip of ebonite supported at some distance from the coil. Both elements of the junctions were made of high resistance wire of very small diameter in order to reduce eddy currents in them. Approximate calculations, based upon the method employed by Howe in calculating the loss in stranded conductors, indicated that any heating of the junction wires due to this cause was negligible. Small pieces of cotton wool were pressed gently between the junction wires and over the joints between them and the copper terminal wires. The coil was supported in a double enclosure, consisting of two wooden boxes. This method of enclosing it was found very effective in protecting it from draughts, and it allowed the coil to be opened up very rapidly for inspection and for cooling between experiments. The junctions were connected in turn to a moving coil galvanometer of the single suspension type. The latter required about 7 microvolts to give 1 cm. deflection on the scale. It was suspended in an antivibration cradle from a bracket upon the wall. The junctions were calibrated by passing an alternating current of low frequency through the coil and measuring the initial rate of rise produced in each per amp.

Preliminary Investigations.

A number of preliminary investigations were necessary, the chief being the following:—

(i.) Means of measuring the high frequency current.

(ii.) The magnitudes and effects of stray capacity currents.

(iii.) Form of heating curves.

(iv.) Uniformity of heating of the wire over its cross-section.

These investigations will not be considered in detail, but the general results will be given. The measurement of the current within an accuracy of 1 per cent. presented little difficulty. Several instruments, whose readings were practically independent of frequency, were designed and constructed. It is not proposed to consider them here.

Stray capacity currents are often a source of considerable error in high frequency measurements. The instruments connected to the circuit often possess capacities which, though they may be neglected at low frequencies, are of importance at high frequencies. One advantage of the calorimetric method is that the results obtained are only in error to the extent to which the capacity currents obtrude upon the main current. With other methods it is possible that a balance may be rendered completely false by stray currents of this nature. It is desirable that, whenever possible, instruments should be connected at points of the circuit which are at approximately earth potential. Unfortunately this cannot always be done. The only course open then is to reduce the capacity of the instruments to a minimum. In the circuit used by the writer there were two points at which capacity leaks were possible, the first at the ammeter, the second at the galvanometer. The first leak was rendered insignificant by connecting the ammeter at a point of the circuit which was practically at earth potential. This could not be done in the case of the galvanometer, and a minute investigation of the possible errors that might occur had to be carried out. When current was passing through the test coil, it was clear that since the junction was not at earth potential a charging current would flow along the junction wires to the galvanometer. The effect of this current would be twofold: (*a*) to modify the actual current flowing into the

coil, (*b*) to cause heating of the junction wires. Experimental investigation showed that both these effects were negligible.

A considerable number of experiments were carried out to determine the form of heating curves. These would be expected to be approximately of an exponental form (see later section). It was found that they were roughly of this nature but that the deviations were not negligible. But what was most remarkable were the variations that might occur between the observations of the rise of temperature of the same point upon different occasions. It was during these investigations that the writer came to the conclusion that great reliance could not be placed upon measurements involving any considerable rise of temperature of the coil—such measurements could not be repeated with sufficient accuracy. The explanation was obviously the variations in the conditions external to the conductor. Yet despite the variations in the rate of rise of temperature when the temperature was moderately different from that of the surroundings, the *initial* rate of rise was found to be remarkably constant for the same current.

The fourth point mentioned above is one of considerable theoretical complexity. Quite inconsistent assumptions have been made during the tests; it has been assumed that the initial rate of rise of temperature is determined by the rate of heat generation at a particular point of the coil; it has also been assumed that the conductor heats uniformly over its cross-section at a particular place. Actually, of course, heat is generated at very different rates over the cross-section of the conductor, the rates being very much more diverse than they are at different points of the coil. Yet calculation shows that it is justifiable to assume uniform heating in the one case and not in the other. Thermal conduction over the cross-section of the conductor is an extremely rapid process, whereas between different parts of the coil it is relatively slow.

Method of Determining the Initial Rate of Rise of Temperature.

The rate of loss of heat at any instant is approximately proportional to the rise of temperature, so long as that rise is not too great.

If a be the rate at which the temperature would rise if there were no loss of heat, and $b\theta$ be the rate at which the temperature would fall if no current were flowing and the coil were at a temperature θ above its surroundings, then

$$d\theta/dt = a - b\theta \quad \ldots \quad (10)$$

whence

$$\theta = \frac{a}{b}\,(1 - e^{-bt}) \quad \ldots \quad (11)$$

Actual heating curves were found to approximate closely, but not with mathematical accuracy, to this form. The approximation, however, was sufficiently exact for the equation to be assumed to apply rigidly in the neighbourhood of the origin. It could therefore be employed to determine a $(=Lt_{t=0}d\theta/dt)$, the initial rate of rise of temperature. If the unit of temperature be that causing a deflection of one galvanometer division, the deflection

$$\partial = \frac{a}{b}(1 - e^{-bt}) \quad \ldots \quad \ldots \quad (12)$$

whence

$$a = \frac{b\partial}{1 - e^{-bt}} = \frac{\partial}{t}\left(\frac{\log e^{bt}}{1 - e^{-bt}}\right) \quad \ldots \quad (13)$$

∂/t is the average rate of rise of temperature during the interval. To obtain the initial rate of rise the average rate must be multiplied by a factor λ given by

$$\lambda = \log e^{bt}/(1 - e^{-bt}) \quad \ldots \quad (14)$$

This factor can be calculated from two successive determinations of deflection and time. In practice a double deflection method was found to be most convenient. A split seconds stop watch was used. One hand of the watch was stopped when the galvanometer deflection was ∂ (usually 10 cms.), the other when the deflection was 2∂. If the times be respectively t and T we have

$$\partial = \frac{a}{b}(1 - e^{-bt})$$

$$2\partial = \frac{a}{b}(1 - e^{-bT})$$

whence

$$(1 - e^{-bT})/(1 - e^{-bt}) = 2 \quad (15)$$

From this relation a curve can be plotted enabling us to determine λ for any ratio of T/t. To obtain this curve, values are given to e^{-bt}, whence values of e^{-bT} can be

calculated at once from equation (15). The corresponding value of T/t is given by

$$T/t = log\ e^{-bT}/log\ e^{-bt} \quad \dots \quad (16)$$

λ is given by the relation

$$\lambda = log\ e^{bt} / (1 - e^{-bt}) \quad \dots \quad (17)$$

The method is obvious from Table II.

In Fig. 10 the relation between T/t and λ is plotted.

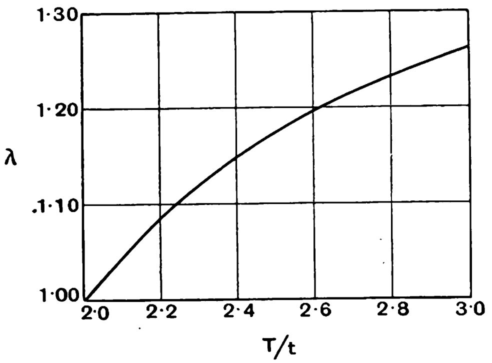


Fig. 10. *Graph for determining the initial rate of rise of temperature from the average rate of rise.*

As an example the following observations may be considered:—

Time for 10 cms. deflection=9.4 secs., for 20 cms.=21.0 secs., T/t=2.235. From curve λ = 1.097. Average rate of rise in the first interval=1.06, whence initial rate of rise is 1.16.

TABLE II.

e^{-bt}	e^{-bT}	λ	T/t
1	1	1	2
0.9	0.8	1.054	2.115
0.85	0.7	1.083	2.194
0.8	0.6	1.115	2.289
0.775	0.55	1.133	2.345
0.75	0.5	1.151	2.411
0.725	0.45	1.169	2.482
0.7	0.4	1.189	2.569
0.675	0.35	1.210	2.672
0.65	0.3	1.231	2.796
0.625	0.25	1.253	2.950
0.6	0.2	1.277	3.152

Typical Experimental Results.

One set of experimental observations is given here to illustrate the method adopted. After each reading the coil was exposed to the air to cool; some time before the next reading was taken the boxes were closed and the whole apparatus allowed to assume a practically uniform temperature. Preliminary experiments showed that it was not necessary to wait until the galvanometer spot had returned to zero. Measurements made with the spot a few cms. from the zero (*i.e.*, coil a few tenths of a degree Centigrade above the surroundings) agreed very closely with those made initially from zero. It was considered desirable to make the actual tests of short duration and reduce inaccuracies in time measurements by taking the mean of a series of observations.

The method of taking an observation was as follows: After adjusting the current and wavelength to convenient values on the adjusting coil, the latter was replaced by the test coil. With the galvanometer spot deflected slightly less than the amount from which it was intended to work as a zero, the transmitting key was closed. As the spot passed the working zero the split seconds stop watch was started; the first hand was stopped when the spot passed a deflection ∂ and the second hand stopped at a deflection 2∂. The current was read and then switched off. The procedure given above was adopted to eliminate inaccuracies due to the inertia of the moving coil of the galvanometer. Occasionally the wavelength was checked on the test coil before switching off the current. Typical log readings are given in Table III.

TABLE III.

JUNCTION III., WAVELENGTH 1,800 METRES.

Zero.	t_8	T_{16}	I	T/t	λ	a	I	a/I^2
2	7.8	20.0	2.90					
2	7.4	19.0	3.02					
2	7.6	19.0	2.99	2.51	1.176	1.239	3.02	.136
2	7.6	19.0	3.06					
2	7.6	18.6	3.06					
2	7.6	19.0	3.09					

t_8 = time for 8 cms. deflections; T_{16}=time for 16 cms. deflections. a/I^2 is the measure of the initial rate of heating per ampere.

This value divided by the corresponding quantity at low frequency gives the ratio R_c/R_0, where R_c is the high frequency resistance of the coil and R_0 its low frequency resistance.

Results Obtained.

The completed results for four different frequencies are recorded in Table IV. and are plotted in Fig. 11.

TABLE IV.

Junct.	L.F.	Wavelength.							
		3,500		3,000		2,500		1,800	
	a/I^2	a/I^2	R_c/R_0	a/I^2	R_c/R_0	a/I^2	R_c/R_0	a/I^2	R_c/R_0
I	.0427	.0864	2.02	.097	2.27	.102	2.38	.131	3.06
III	.0429	.0888	2.07	.099	2.30	.106	2.47	.136	3.17
IV	.0371	.0924	2.48	.104	2.80	.113	3.05	.141	3.80
V	.0336	.151	4.77	.175	5.24	.200	5.94	.242	7.22
VIa	.0325	.108	3.33	.120	3.69	.132	4.07	.165	5.07

Positions of junctions.

I turn 60 (middle of coil)
III turn 15
IV turn 9
V turn 1 (end of coil)
VIa turn 4

Examination and Criticism of Results.

Over the range of frequencies investigated the experiments were successful in demonstrating the approximate magnitude of the increase of resistance due to the end effect. Beyond this, it is claimed that the determination of the initial rate of rise of temperature is, in all cases, a more satisfactory way of carrying out a calorimetric test than the determination of the rise of temperature in a definite time. The experience is undoubtedly that the latter determination is open to many errors from which the former is free.

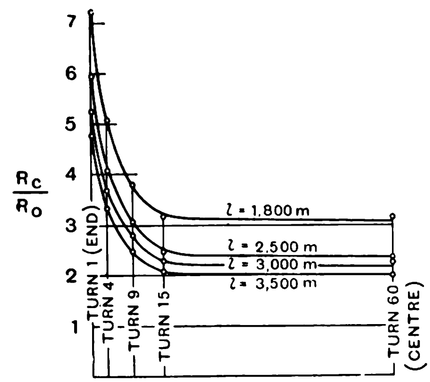


Fig. 11. *Distribution of loss in experimental coil.*

The magnitude of the end effect is considerable, as the curves of Fig. 11 show. It is, however, as might be expected, very localised. (The rise of temperature of junction III.—only one-quarter of the way from the end to the centre of the coil—was very little greater than the rise of junction I. From this point to the end the rise of resistance is most marked.) The total resistance of the coil is consequently increased—at the frequencies used—by about 12 per cent.

The generating set employed was limited in wavelength control and the range of frequencies actually used is too limited for extensive deductions to be made. The relations between the various curves, however, merit examination.

As far as the experiments go, no great variation (apart from the general rise of resistance with frequency) in the magnitude of the end effect was experienced. This is demonstrated in Table V.

TABLE V.

Wave-length.	R_c/R_0 at centre of coil—from curve.	R_c/R_0 average.	Ratio.
1,800	3.05	3.38*	1.11
2,500	2.35	2.66	1.13
3,000	2.18	2.44	1.12
3,500	2.00	2.24	1.12

Such a result would be expected if the field distribution were independent of the frequency. One would expect this for frequencies well below the resonant frequency of the coil, if the diameter of the wire is small compared with the dimensions of the coil, that is to say, so long as the field is not greatly modified by either variation of the current distribution along the length of the coil or by reaction of the eddy field upon the main field.

Again, the experimental results seem to indicate a lower actual resistance but a greater rate of rise of resistance with frequency than is suggested by theoretical investigations. Howe in his paper, "The High Frequency Resistance of Wires and Coils,"† gives a curve connecting R_c/R_0 and $\beta\tau$ (Fig. 6 of that paper, reproduced here as Fig. 12), where $\beta = 2\pi\sqrt{f\mu/10^9\rho}$ and τ = thickness of conductor, if rectangular. For round wires it is suggested that τ should be taken as $.886d$ and μ as $\sqrt{S\tau}$ where S =

* The calculated value of R_c/R_0 average for this coil at 1,800 metres from Butterworth's formula is 3.41, a very good agreement.

† *Proceedings, I.E.E.*, Vol. 58, p. 152.

number of turns per cm. For the coil used by the writer d=.0914 cm., τ=.081 cm., S= 119/15.7, whence $S\tau$=.613, $\sqrt{S\tau}$=.783 and $\beta\tau = .00965\sqrt{f}$. The values of $\beta\tau$, therefore, for wavelengths 3,500, 3,000, 2,500, and 1,800 are respectively 2.82, 3.05, 3.34, 3.94. It will be seen from the curve that $R_c/R_0 = \beta\tau$ when $\beta\tau > 2.5$. The corresponding values obtained experimentally (at the centre of the coil) are 2.00, 2.18, 2.35, 3.05. Doubt has been expressed regarding the validity of the assumption that spacing is equivalent to a reduction in the permeability in the ratio $\sqrt{S\tau}$. The differences may be explained if this assumption is incorrect.

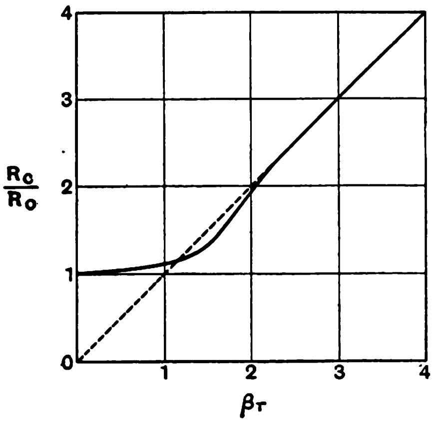


Fig. 12. *Curve from Howe's paper on "The High Frequency Resistance of Wires and Coils."*

The experimental results also suggest a rise of resistance more than proportional to the square root of the frequency. Comparing the values for wavelengths 1,800 and 3,500 we have f_2/f_1=1.95; $\sqrt{f_2/f_1}$=1,396; R_2/R_1 =1.525; indicating a rise of resistance rather greater than the square root of the rise of the frequency.

It would perhaps be unwise to generalise from these results, although they differ somewhat from theoretical values. The experiments call for repetition upon coils of different shapes and sizes.

So long as one may assume that either the end effect is small or that the average resistance bears a constant ratio to the resistance at the centre, measurements upon the resistance of the coil as a whole (what one may call its "mass-resistance"), may afford valuable information. Thermojunctions placed at the centre may be assumed to give the resistance of long coils, if the initial rate of heating method is adopted. If, however, the coil is allowed to heat for a sensible length of time the reading of a thermojunction placed at the centre cannot give very reliable information. Junctions must, in this case, be placed at several points on the coil.

Another calorimetric method of test, evolved by the writer and described below, is capable of giving the mass-resistance much more expeditiously than thermojunctions.

Second Calorimetric Method of Determining High Frequency Resistance.

The resistance of a copper conductor to a direct current rises by about 0.4 per cent. for a rise of temperature of 1°C. This rise of resistance may be employed to determine the rise of temperature. The rate at which a conductor heats when an alternating current is passed through it is proportional to the square of the current and to the resistance which the conductor offers to the current. The same conductor may offer very different resistances at the same time to different currents. Thus the coil used in the tests already described, offered a resistance of about 3 ohms to a current at a frequency of 150,000. Had a direct current of 1 milliampere been superposed upon the alternating current, only about a millivolt direct pressure would have been required; its resistance to direct current is only about 1 ohm. This direct current resistance can be measured with a Post Office box even while the alternating current is passing through the coil; the galvanometer is not affected by an alternating current. Such an experiment, however, is not really practical. In the first place the high frequency voltage across the coil is considerable and the Post Office box would not stand this voltage being applied to it and, secondly, the connection of the box would modify the value of the current through the coil. The first objection may be met by the insertion of properly designed choking coils in the connections to the bridge; that, however, would add a considerable amount of undesirable resistance. It is clear that if satisfactory working is to be obtained the bridge must be connected to two points at

the same, or practically the same, potential. In order to reduce capacity effects, these points should be at earth potential. Both of these conditions can, in general, be fulfilled.

We will assume for the present that two identical test coils are available. They are placed at some distance from one another, so that one coil cannot affect the current distribution in the other and they are connected as shown in Fig. 13. AB is a low resistance wire, CF and DF two equal high resistance wires having a negligible temperature coefficient, of sufficient section to carry the test current through one of the coils. (No. 22 S.W.G. Eureka wires, 3 metres long, were found satisfactory for the original test and adjustment coils.) If the high frequency current be passed between F and E it divides equally between the two branches, and points C and D are at the same potential and only a few volts, at the most, from earth. The Post Office box is connected between these two points. If R be the resistance of one of the coils and W the resistance of one of the wires, the measured resistance R' is $2RW/(R+W)$. If R increases by a small amount dR the change dR' in R' is given by

$$dR' = 2\left(\frac{W}{R+W}\right)^2 \cdot dR \qquad \ldots \quad (18)$$

That is to say, so long as the change in R is small the change in R' is proportional to it. It is quite unnecessary for dR to exceed 1 per cent. of R and in this case the above expression is sufficiently accurate. It can be corrected if greater accuracy is required. Since the measurements are always relative, the constant can be neglected. The unit of temperature may be taken as that which causes a change of R' of, say, $1/n$ per cent.

The initial rate of rise of temperature method is still employed.

The arrangement was tested for two similar coils having a resistance of about 2 ohms each and consisting of 87 turns of No. 24 S.W.G. copper. Suitable Eureka wires were used and the resistance measured by the Post Office box between C and D was 3.83 ohms. (The plugs out were: ratio 1,000 and 10; resistance 383.) The balance was then disturbed by setting the bridge to 3.84 ohms, deflecting the galvanometer spot (a shunt was employed). The transmitting key was depressed and at the same instant the stop watch was started. The galvanometer spot immediately began to approach the zero; when it was sufficiently near, the shunt was removed and the exact instant of balance recorded by stopping the first hand of the watch. The shunt was replaced, the balance disturbed by setting the bridge to 3.85 ohms and the instant of balance recorded as before with the second hand of the watch.

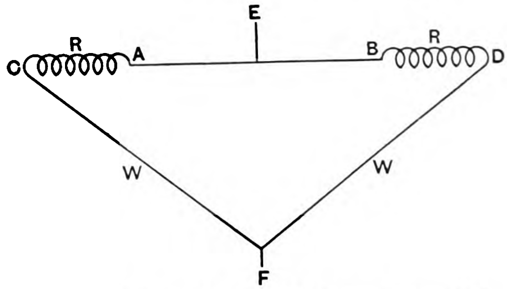


Fig. 13. *Circuit for second calorimetric method of determining high frequency resistance.*

Repeating with a low frequency current the ratio of high to low frequency resistance was determined.

Conclusion.

Time has not permitted the writer to pursue the experiments outlined in this article to the extent he would have wished. Sufficient has, however, been accomplished to show the practicability of the methods employed and to obtain certain results of value. It should be clearly recognised that the measurements made are of true loss in the copper conductor itself. The time of experiment was usually so short that there was no sensible exchange of heat between the conductor and its surroundings. It would be interesting to compare the results of such experiments with measurements of the effective resistance of coils determined, say, by the decrement which they introduce in an oscillating circuit. Measurements of the latter type would include incidental loss in the surroundings. The comparison should afford information of value in improvement in design, which must necessarily be hampered if the distribution of such losses as occur is unknown.

A Constant Frequency Source and its Frequency Measurement.

By S. W. C. Pack, Wh.Sch., A.C.G.I., B.Sc., D.I.C.

THE necessity for a reliable frequency standard for making accurate radio measurements in the laboratory is well known. Some measurements were recently made on the frequency drift of valve oscillators when variations took place in the circuit constants and other conditions, the *L*,*C*, values in the oscillatory circuit remaining the same. In this case it was essential to have a constant frequency source, the frequency of which could be relied on to within a few parts in a 100,000. A valve-maintained tuning fork at once presents itself to our minds, and it is proposed to describe in some detail the experimental arrangements of such a fork together with the difficulties encountered in successfully maintaining it, and the arrangement for the accurate determination of the frequency of the maintained fork. The experiments were carried out in the Radio Laboratories of the City and Guilds Engineering College under the supervision of Professor C. L. Fortescue, M.A., and Professor E. Mallett, D.Sc.

I. The Valve-Maintained Fork.

The question as to the suitability of a valve-maintained fork as a constant frequency source has been investigated by D. W. Dye* and also by H. Dadourian,† pretty thoroughly. Dye maintained a fork of 1,000 cycles in the manner first suggested by Eccles ‡ but with slight modification.

The principle of maintenance is as follows: Two permanent magnets, each wound with a suitable number of turns, are placed one attracting each prong of a tuning fork the coils being connected into the anode and grid circuits of a thermionic valve as shown in Fig. 1. Now imagine the fork set in vibration. Suppose the prongs of the fork are on their outward traverse; then an E.M.F. will be induced in the grid coil and will be applied to the grid of the valve. This will vary the anode current, or in other words will produce a change of ampere-turns on the anode magnet. If the coil is connected up in the correct direction the anode magnet will be made to attract its prong and so assist in the outward traverse of the prongs. The same process occurs when the prongs are on the inward traverse the

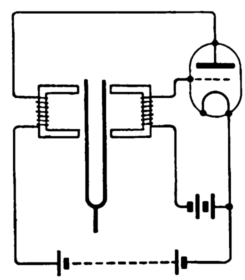


Fig. 1. *Simple circuit of valve-maintained tuning fork.*

anode magnet assisting its prong inwards, as the conditions are now reversed. Assuming therefore that we allow suitable constants in the circuit the fork will be maintained. One of the first difficulties that presents itself is the fact that we may not be able to get sufficient turns on the magnets; it is then necessary to adopt step-up transformers to be connected to each magnet coil and in this way we can match impedances very much better. The motional impedance of the fork is matched with the low impedance side of the transformer, and the high impedance side of the transformer is matched with the internal resistance of the valve. The arrangement for the transformers is indicated in Fig. 2.

The mathematical theory for the valve-maintained tuning fork has been dealt with very fully by Butterworth* and Hodgkinson†; a simple treatment as developed by Dr. Mallett is given later on in this article.

* *Proc. Roy. Soc. A.*, Vol. 103, p. 204, 1923.
† *Phys. Review*, Vol. 13, pp. 337-359.
‡ *Phys. Soc. Proc.*, Vol. 31, pp. 269.

* *Phys. Soc. Proc.*, Vol. 32, pp. 345-360, 1920.
† *Ibid.*, Vol. 38, pp. 24, 1924.

II. Constancy of the Valve-Maintained Fork.

Experiments were made by Dye and Dadourian on the valve-maintained fork to investigate the constancy of frequency under various conditions. Their results serve to show that the fork is really quite suitable as a frequency standard. The chief factor in causing variation is temperature and it is advisable to keep the mounted fork in a constant temperature cell. Dye found that the frequency decreased by 1.15 parts in 10,000 for an increase in temperature of 1° C. A 1,000-cycle fork was used in that

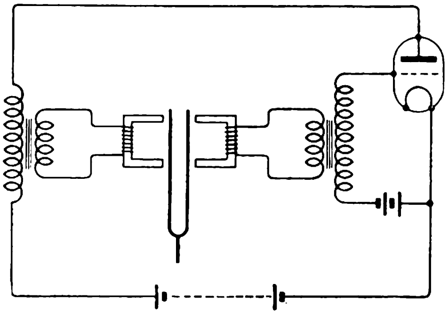


Fig. 2. *Circuit of valve-maintaining tuning fork using transformers.*

case. Other variations only made small alterations in the frequency. The anode and filament voltages could be suitably arranged so that a 10 per cent. change in either direction of the anode current or anode voltage caused less than 1 part in 1,000,000 change in frequency. Changing the valve produced a variation of only 1 part in 100,000. The flux density should be kept fairly constant as it was found that a change of only 1 per cent. gap flux for a B. 2,200, caused a frequency change of 6.5 parts in 1,000,000. The frequency of the fork also depends upon the power output from the system, and the method of taking the power varies to some extent the frequency variation. This matter of power output will be referred to later.

Dr. Mallet* has shown that there is considerable distortion in the resonance curve for an electrically driven fork at large amplitudes, so it is essential that the amplitude of the maintained fork should be kept moderately small in order to keep the frequency constant.

* *Phys. Soc. Proc.*, May, 1927.

III. The Selection and Mounting of Fork.

The most suitable frequency for the fork for use in comparing valve oscillator frequencies of a range varying from, say, a few hundred cycles upwards to the radio frequencies, was found to be 128 cycles. Maintaining a fork of such low frequency however is a matter which calls for careful design of the operating valve circuit, mainly because the induced E.M.F. at this frequency is so small. In addition the decay factor of low frequency forks is often just as high as in the case of the high frequency forks, though the fork used in the present case had quite a small damping when free. The dimensions of this 128-cycle fork were: $0.8 \times 0.47 \times 17$ cms., the distance between the prongs being 1.42 cms. For use as driving magnets some old phones were stripped and mounted on wooden blocks so as to bring the pole pieces to operate on the prongs of the fork, one to each prong. The method of mounting is illustrated in the photographs in Fig. 3. The picture also shows the bottom half of the constant temperature cell. This consisted of a cardboard box and lid made as airtight as possible and padded with cotton waste. A disused quarter plate was cleaned and inserted in one end so that a window was formed through which a thermometer inside the cell could be viewed. Leads were taken from the driving magnets to four terminals at the end on the outside of the box. The box with the fork inside was put inside a small cubicle which was in the laboratory and quite near to the bench supporting the other apparatus for the maintenance of the fork. The door of this cubicle could be kept shut and the temperature of the fork thus kept constant to within about .5°F. in normal weather. Leads were taken from the cell through holes in the cubicle walls to the transformers and apparatus on the bench. The position of mounting the driving magnets can be seen in the photograph. The phones with the terminals on top are the 120-ohm ones which were finally adopted as driving magnets, some smaller ones of 4,000 ohms were used but were not suitable for reasons explained later. Using a D.E.R. Marconi valve with either type of magnets and trying various values of grid bias and anode voltage the fork was not maintained nor did there seem to be any tendency towards maintenance.

The probability is that there were not enough turns on the low resistance magnets and not sufficient flux in the case of the high resistance magnets.

The phones had first been temporarily mounted near the extremities of the prongs the speed of a point near the extremity. If we take the phones right to the base of the prong the damping due to the magnets is then zero but there will be no attraction of the prongs. Hence there will be a compromise between the two factors of damping

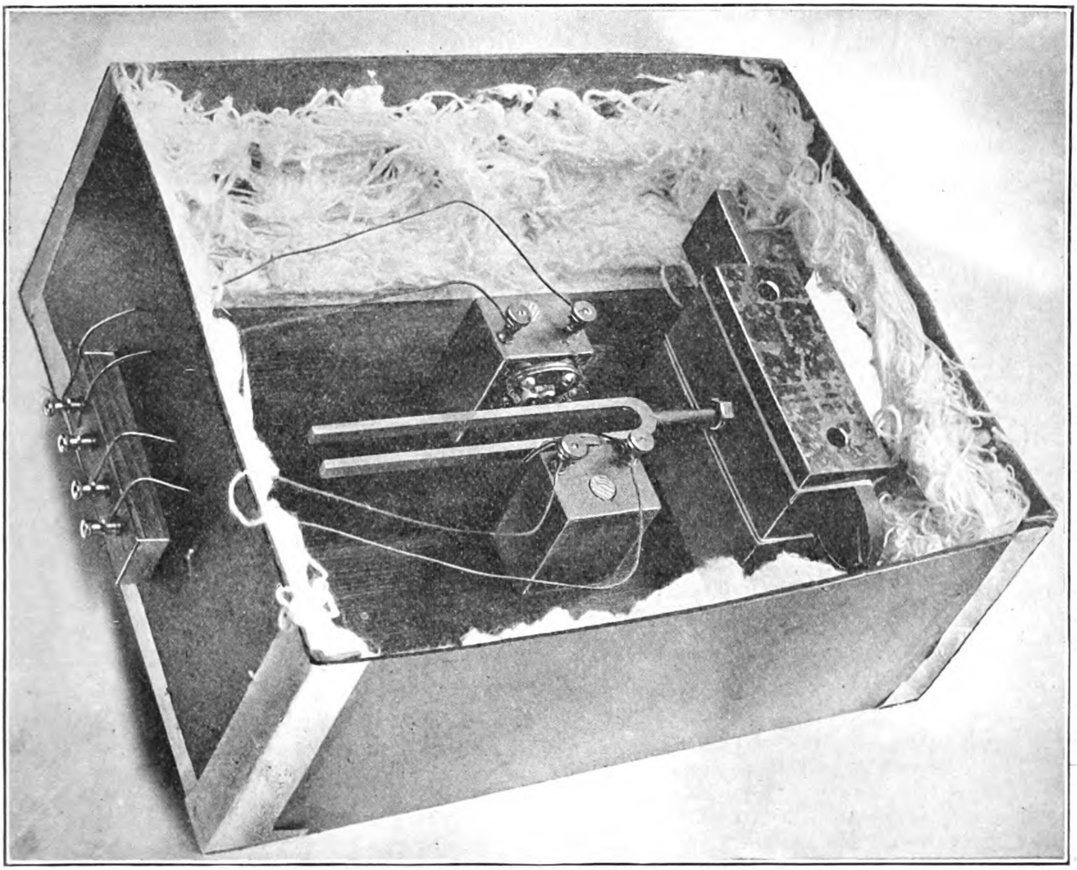


Fig. 3. *Mounted tuning fork and driving magnets enclosed in one-half of padded cell.*

but tests were now made to see the effect of moving the phones along the prongs. The effect was at once noticeable and by listening to some headphones inserted in the valve anode circuit one could adjust the position of the magnets to give the most satisfactory conditions. The reason for the improvement is due to the reduction in the damping of the vibrations, the nearer the phones are to the base of the fork. This is because the speed of a point of the fork near the prong base is relatively lower than and attraction. By experimenting the best position for the phones was found to be about two-thirds of the way along the prong towards the base and they were then permanently fixed in this position. There now seemed to be more of a tendency to maintain.

Various other valves were tried but without any improvement except for a Mullard P.M.1 H.F. which reduced the damping factor though not actually maintaining the fork. This may have been accounted for

by the fact that the ratio μ/R_0 is high and this is important as may be seen in the following theory:—

IV. Theory of Maintained Fork.

The following simple treatment of the valve-maintained tuning fork has been suggested by Dr. Mallett and enlarged upon by the author, and enables us to obtain an idea of the limitations imposed in maintaining the fork.

The equivalent electrical circuit for the ordinary case is given in Fig. 4(*a*) and for the transformer case in Fig. 4(*b*).

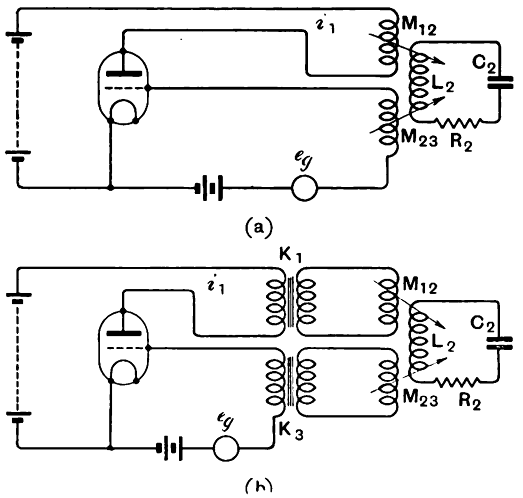


Fig. 4. *Equivalent electrical circuit of valve-maintained tuning fork,* (a) *without transformers,* (b) *with transformers.*

We will work out the transformer case as this applies to the ordinary case as well when the transformer ratios are put equal to unity.

Imagine an E.M.F. of value e_g injected into the grid circuit to maintain oscillations.

ω = $2\pi f$, where f = frequency.
v_g = E.M.F. applied to grid.
i_2 = imaginary current in the tuning fork equivalent circuit.
Z_2 = impedance of this equivalent circuit $= R_2 + jX2$.
i_1 = anode current.
Z_1 = impedance of anode coil $= R_1 + j\omega L_1$.
R_0 = internal resistance of valve.
μ = amplification factor of valve.
M_{12} = imaginary mutual between anode-coupled driving coil and tuning fork.
M_{23} = imaginary mutual between grid-coupled driving coil and tuning fork.
K_1 = transformation ratio of anode transformer.
K_3 = transformation ratio of grid transformer.

Now $v_g = e_g + j\omega M_{23}.i_2.K_3$

and $i_2 = \dfrac{j\omega M_{12} i_1 K_1}{Z_2}$

but
$$i_1 = \frac{\mu.v_g}{R_0 + Z_1 + \dfrac{\omega^2 M_{12}^2}{Z_2}.K_1^2}$$
$$= \frac{\mu\left(e_g - \dfrac{\omega^2.M_{12}.M_{23}.K_1.K_3.i_1}{Z_2}\right)}{R_0 + Z_1 + \dfrac{\omega^2 M_{12}^2 K_1^2}{Z_2}}$$
$$\therefore\ i_1\left(R_0 + Z_1 + \frac{\omega^2 M_{12}^2.K_1^2}{Z_2}\right) + i_1\left(\frac{\mu.\omega^2.M_{12}.M_{23}.K_1.K_3.}{Z_2}\right) = \mu.e_g$$

Now the condition for self maintenance is that $e_g = 0$.

Hence our condition is that
$$(R_0 + Z_1)Z_2 + K_1^2.\omega^2.M_{12}^2 + \mu.\omega^2.M_{12}.M_{23}.K_1.K_3 = 0 \quad \ldots \quad (1)$$

By equating the unreals we can determine the frequency of oscillation.
$$R_2.j\omega L_1 + (R_0 + R_1).j.X_2 = 0$$

We notice that this does not involve K_1 or K_3, hence the frequency is unaltered by inserting transformers.
$$X_2 = -\frac{R_2\,.\,\omega L_1}{R_0 + R_1}$$
i.e.,
$$\left(\omega L_2 - \frac{1}{\omega C_2}\right) = -\frac{\omega R_2 L_1}{R_0 + R_1}$$
$$\omega^2\left(L_2 + \frac{R_2.L_1}{R_0 + R_1}\right) = \frac{1}{C_2}$$
Hence
$$\omega = \frac{1}{\sqrt{L_2 C_2\left(1 + \dfrac{R_2}{R_0 + R_1}\cdot\dfrac{L_1}{L_2}\right)}} \quad (2)$$

We must remember that R_2, L_2, and C_2 are all imaginary constants of the equivalent electrical circuit. Now from the equation for frequency derived as above and given in equation (2) we see that the correction term
$$\frac{R_2}{R_0 + R_1}\cdot\frac{L_1}{L_2}$$

is small and hence we may say approximately

$$\omega L_2 = \frac{1}{\omega C_2}$$

i.e., $\underline{X_2 = 0}$

Thus simplifying the work and obtaining the following equation :—

$$(R_0 + R_1) R + \omega^2.M_{12}^2.K_1^2 + \mu.\omega^2.M_{12}.M_{23}K_1.K_3 = 0 \quad (3)$$

From this we get the all important fact that M_{12} and M_{23} must be opposite in sign. Hence the fork will only be maintained if the coils are connected up in the correct direction relatively to one another.

If the driving coils and magnets are similar to one another $M_{12} = M_{23} = M$ (numerically).

R_1 is small compared to R_0

Hence approximately

$$\underline{\omega^2.M^2.K_1(\mu.K_3 - K_1) = R_0 R_2} \quad \ldots \quad (4)$$

From the point of view of maintaining the fork we want the critical value of ωM as small as possible.

$$\underline{\omega^2 M^2 = \frac{R_0 R_2}{K_1(\mu K_3 - K_1)}} \quad \ldots \quad (5)$$

and should be as small as possible.

Mechanical Consideration.

We can work out the theory in much the same way from a consideration of the force factors at the prongs of the fork (the force per unit of current in the driving coils) and the mechanical impedance of the prongs.

The mechanical impedance of a prong is merely its opposition to motion when operated upon by a vibromotive force. The opposition consists of mechanical resistance and mechanical reactance. The mechanical resistance is composed of acoustic and frictional resistance which we may take as being proportional to the speed; hence it will be expressed in dynes per cm. per sec. or absolute ohms (*i.e.*, 10^{-9} ohms). The mechanical reactance is composed of the inertia and stiffness of the prong and will be expressed in the same units. Hence the mechanical impedance which is the vector sum of the mechanical resistance and reactance will be expressed in the same units.

If r = mechanical resist. in dynes/cm./sec.
m = equivalent mass of prong (referred to later) in grms. (or dynes/cm./sec²).
s = stiffness in dynes/cm.

Then Mechanical Impedance

$$= r + j(\omega m - s/\omega) \text{ dynes/cm./sec.}$$

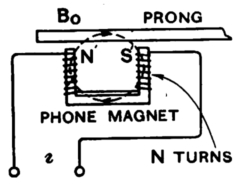


Fig. 5. *To illustrate mechanical consideration.*

Let B_0 = flux density due to permanent magnet (lines/cm²).
b = flux density due to current through coils.
N = total number of turns on poles.
$\mathcal{R}$ = reluctance of flux path (Oersteds).
a = cross sectional area of each pole (cm²).
i = current in coils, (absolute C.G.S. units).

The direction of b depends upon the direction of i. We will, however, consider it positive.

$$\text{Pull on prong} = 2 \times \frac{(B_0 + b)^2}{8\pi} \times a \text{ dynes.}$$

$$= \frac{a}{4\pi}(B^2 + 2B_0 b + b^2) \text{ dynes.}$$

$$\text{Fluctuating pull} = \frac{a}{4\pi}(2B_0 b + b^2) \text{ dynes.}$$

$$= \frac{a}{4\pi}.2B_0 b + \frac{ab^2}{4\pi} \text{ dynes.}$$

Now, if $B_0 >> b$ the term involving b^2 is negligible.

Fluctuating pull due to current i

$$= a.B_0.b/2\pi \text{ dynes.}$$
$$= f_i \text{ (say).}$$

We will neglect fluctuation of $\mathcal{R}$ and assume it to be constant.

Total flux in one gap due to current i

$$= a.b = 4\pi.i.N/\mathcal{R} \text{ (Maxwells).}$$

neglecting the fluctuation of $\mathcal{R}$ with i.

Hence, $$f_i = \frac{B_0}{2\pi} \times \frac{4\pi . i . N}{\mathcal{R}}$$

$$= \frac{2NB_0}{\mathcal{R}} . i$$

$$f_i = A.i \text{ dynes}$$

where A is the force factor (force per unit current).

Hence, $A = 2B_0N/\mathcal{R}$ for one prong.

We may liken the attracted prong to a mass "m" grms. attracted by a magnet and attached to a spring of stiffness "s" dynes/cm., there being a mechanical resistance to motion of "r" dynes per cm. per sec., the resistance varying with the velocity "u" of the mass. (See Fig. 6(a).) The electrical analogy is a circuit of inductance L, capacity C, and resistance R, with an applied E.M.F. of e. (See Fig. 6(b).)

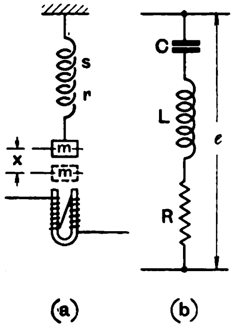


Fig. 6. (a) *Mechanical analogy.*
(b) *Electrical analogy.*

In the electrical case the current

$$i = \frac{e}{R + j\left(\omega L - \frac{1}{\omega C}\right)} = \frac{e}{Z}$$

Now r is equivalent to R.
m is equivalent to L.
s is equivalent to $1/C$.

Hence velocity of prong

$$u = \frac{f_i}{r + j\left(\omega m - \frac{s}{\omega}\right)} = \frac{f_i}{z}$$

Where z is the mechanical impedance of prong. If x is the displacement of prong from the mean position, we have

$$\dot{x} = \frac{f_i}{z} = \frac{A.i}{z}$$

$$\dot{x} = \frac{A}{z} . i$$

Generated E.M.F.

The reluctance of the flux path will decrease when prong is displaced by a distance x towards the magnet poles.

i.e., Reluctance is $\left(\mathcal{R} - \frac{2x}{a}\right)$ (Oersteds).

Now, generated E.M.F. is the rate of change of linkages with respect to time.

$$\text{Generated E.M.F.} = N\frac{d\Phi}{dt}$$

where Φ = total flux (Maxwells).
N = total turns.

$$\text{Total flux} = \frac{\text{Magnetomotive force}}{\text{Reluctance}}$$

Hence, $$\Phi = \frac{M.M.F.}{\mathcal{R} - \frac{2x}{a}}$$

Generated E.M.F.

$$= N\frac{d}{dt}\left[\frac{M.M.F.}{R}\left\{1 + \frac{2x}{\mathcal{R}.a}\right\}\right]$$

since $2x/a$ is small compared with R.

Generated E.M.F.

$$= N\frac{d\left(B_0.a\left\{1 + \frac{2x}{\mathcal{R}a}\right\}\right)}{dt}$$

$$= \frac{N . B_0 a.2.\dot{x}}{\mathcal{R}.a}$$

$$= \frac{2B_0N}{\mathcal{R}} . \dot{x}$$

$\therefore$ Generated E.M.F. $= A.\dot{x}$

Motional Impedance.

Now, the effect of the prong vibrating in the magnetic field is equivalent to increasing the impedance of the magnet coil. The increase is referred to as the "motional impedance."

If the normal impedance of a magnet coil

with current i is Z_1 then total E.M.F. across winding

$$= Z.i + A.\dot{x}$$
$$= Z.i + \frac{A^2.i}{z}$$
$$= \left(Z + \frac{A^2}{z}\right).i$$

Hence, motional impedance $= A^2/z$.

Now, returning to the complete circuit of the valve-maintained tuning fork and treating it in a somewhat similar manner as previously, we have :—

If

A_1 is the force factor of the anode-coupled prong,

A_3 is the force factor of the grid-coupled prong.

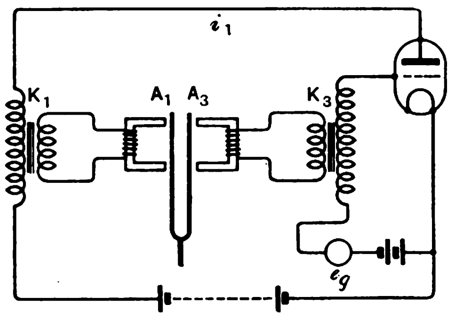


Fig. 7. *To illustrate mechanical consideration of valve-maintained tuning fork theory. False factors* A_1 *and* A_3.

Now

$$v_g = e_g + K_3 \times (A_3\dot{x})$$
$$= e_g + K_3 \times \left\{A_3 . \left(\frac{A_1.i_1}{z}.K_1\right)\right\}$$
$$= e_g + \frac{K_1K_3A_1A_3\,i_1}{z}$$

and
$$i_1 = \frac{\mu v_g}{R_0+Z_1+K_1^2\left(\frac{A_1^2}{z}\right)}$$

$$i_1 = \frac{\mu\left(e_g + \frac{K_1K_3A_1A_3\,i_1}{z}\right)}{R_0 + Z_1 + K_1^2\left(\frac{A_1^2}{z}\right)}.$$

$$\therefore\ i_1\left(R_0+Z_1+\frac{K_1^2A_1^2}{z}\right) - i_1\left(\mu.\frac{K_1K_3A_1A_3}{z}\right) = \mu e_g$$

Now, the condition for self maintenance is that $e_g = 0$.

Hence our condition is that :—

$$(R_0+Z_1)z+K_1^2A_1^2 - \mu.K_1K_3A_1A_3=0 \qquad (6)$$

A_1, A_2, and z are complex quantities but if $A_1=A_2=A$ (say) as in the present practical case, that is the force factor at each prong in the same, we may say approximately that the numerical relationship is :—

$$A^2 = \frac{R_0.r}{K_1\,(\mu K_3 - K_1)} \quad \ldots \quad (7)$$

by neglecting Z_1 which is small compared to R_0.

r may be defined as the mechanical impedance at resonance.

Equations (6) and (7) are analogous to equations (3) and (5) respectively.

From equation (7) we now know the limiting value of force factor A necessary to maintain the fork. Our actual A is given by substituting the values of the constants in

$$A = \frac{2B_0N}{\mathcal{R}}$$

We must then make B_0 and N sufficiently large and $\mathcal{R}$ sufficiently low to get a high enough value of A to satisfy the limiting condition.

For easy maintenance of course we want the critical value

$$\frac{R_0r}{K_1(\mu K_3 - K_1)}$$

to be as small as possible.

Now r is a constant and with a given valve μ, R_0 are constants. Hence $K_1(\mu K_3 - K_1)$ should be a maximum, K_1 and K_3 being two independent variables. The condition for this is :—

$$K_1 = \frac{\mu K_3}{2}$$

which gives us the best relations between the values K_1 and K_3.

V. Calculation on the Fork Constants.

Lord Rayleigh* has shown that the "equivalent mass" of a prong of a tuning fork may be taken as approximately equal to

* *Theory of Sound.* By Lord Rayleigh. Vol. I., p. 235.

one-quarter the total mass of the prong. The constants of a fork are analogous to those of a telephone diaphragm which have been dealt with by Kennelly.*

Hence equivalent mass " m "

$$=\tfrac{1}{4}\times(0.8\times0.47\times17)\times7.8 \text{ grms.}$$

since the density of mild steel is 7.8 grms/c.c.

$$m=12.5 \text{ grms.}$$

stiffness " s " $=m.\omega_0^2$

$$=12.5\times128^2\times4\pi^2$$

$$s=6.315\times10^6 \text{ dynes/cm.}$$

The amplitude of the fork was found to decrease to half of its initial value in about 6 secs.

If " Δ " is the decay factor

$$\therefore \qquad \varepsilon^{-\Delta.6}=0.5$$

$$\Delta=0.115\left[=\frac{r}{2m}\right]$$

Mechanical Impedance at Resonance " r."

$$r=\Delta\,.\,2m$$

$$=0.115\times25$$

$$r=2.88 \text{ dynes/cm./sec.}$$

Minimum value of A necessary to maintain fork

$$=\sqrt{\frac{R_0r}{K_1(\mu K_3-K_1)}}$$

Without transformers

$$A=\sqrt{\frac{R_0r}{\mu-1}}$$

For a D.E.R. take $\begin{cases}\mu=9\\ R_0=32{,}000 \text{ ohms.}\end{cases}$

$$=32{,}000\times10^9 \text{ abohms}$$

$$\text{minimum } A=\sqrt{\frac{32{,}000\times10^9\times2.88}{8}}$$

$$=3.392\times10^6 \text{ dynes/abamp.}$$

Having found the minimum value of A necessary to maintain fork, if we know the flux density B_0 and the reluctance $\mathcal{R}$ of the flux path in each prong we can determine the number of turns which are necessary on the driving magnets.

The reluctance of the flux path is mainly composed of that of the two air gaps between the prong and the poles. Each air gap is 0.15 mm. long and the area of cross section of the pole pieces is 1×0.15 cm².

$$\text{Hence} \quad \mathcal{R}=\frac{2\times0.15}{1\times0.15}=2 \text{ (Oersteds).}$$

Roughly the flux density of the air gap was found to be 600 lines/cm². Hence substituting in the equation

$$A=\frac{2B_0N}{\mathcal{R}}$$

we find that the number of turns necessary is

$$N=\frac{3.392\times10^6\times2}{2\times600}=5{,}650 \text{ turns.}$$

The number of turns on the driving magnets used was about 1,000, which is well below the estimated need for 5,650 turns. It is obviously necessary therefore to use transformers. Some high resistance phones were tried as driving magnets, having a larger number of turns, but in this case the flux seemed very weak and owing to the small and flimsy construction of the magnets the reluctance was probably very high. The number of turns on these high resistance phones was not sufficiently high, apparently, to make up for the low flux and high reluctance, for the fork was not maintained when using them without transformers. With transformers the impedances did not match up suitably and fork was only weakly maintained. The low resistance phones were therefore adopted and various types of transformers which were available were tried.

From the theory we see also that it is best to use a valve with high " μ " relative to the " R_0 ". The effect of doing this will not be quite so advantageous as we might at first expect owing to the effect of the root sign in the term

$$\sqrt{\frac{R_0r}{K_1(\mu K_3-K_1)}}$$

Similarly when transformers are used the tendency for the K values to decrease the limiting value of " A " is minimised by the presence of the root sign. Again in using transformers we are introducing extra copper and iron losses, so that it is not just sufficient to introduce any transformers but we must also be careful in our selection.

After numerous trials with various types

* *Electrical Vibration Instruments.* By A. E. Kennelly. Chapters IV. to X.

the tuning fork was strongly maintained by using two fairly large transformers which may be seen in the photograph in Fig. 8. The one in the anode circuit is provided with a number of tappings. The best relation between the transformer ratios as found in the theory is $K_1 = \mu K_3/2$, but owing to practical difficulties this relation could not be attained. It was found necessary to use rather massive transformers to reduce the power loss which would otherwise take place in a small transformer. This is because the frequency, 128 cycles, is fairly low, and to produce the necessary voltage we must have a suitable flux density.

With small transformers there will be a risk of saturation and the permeability will drop to a low value. As there was not a big selection of large transformers available the relation $K_1 = \mu K_3/2$ could not be held to.

However, the fork was maintained quite strongly enough with the transformers shown in the photograph in Fig. 8, and if the relation between the K's had been held to strictly, the amplitude of vibration would have been so large as to lead to frequency distortion as mentioned previously. Actually the grid transformer ratio was about 70 to 1 and the tappings on the anode

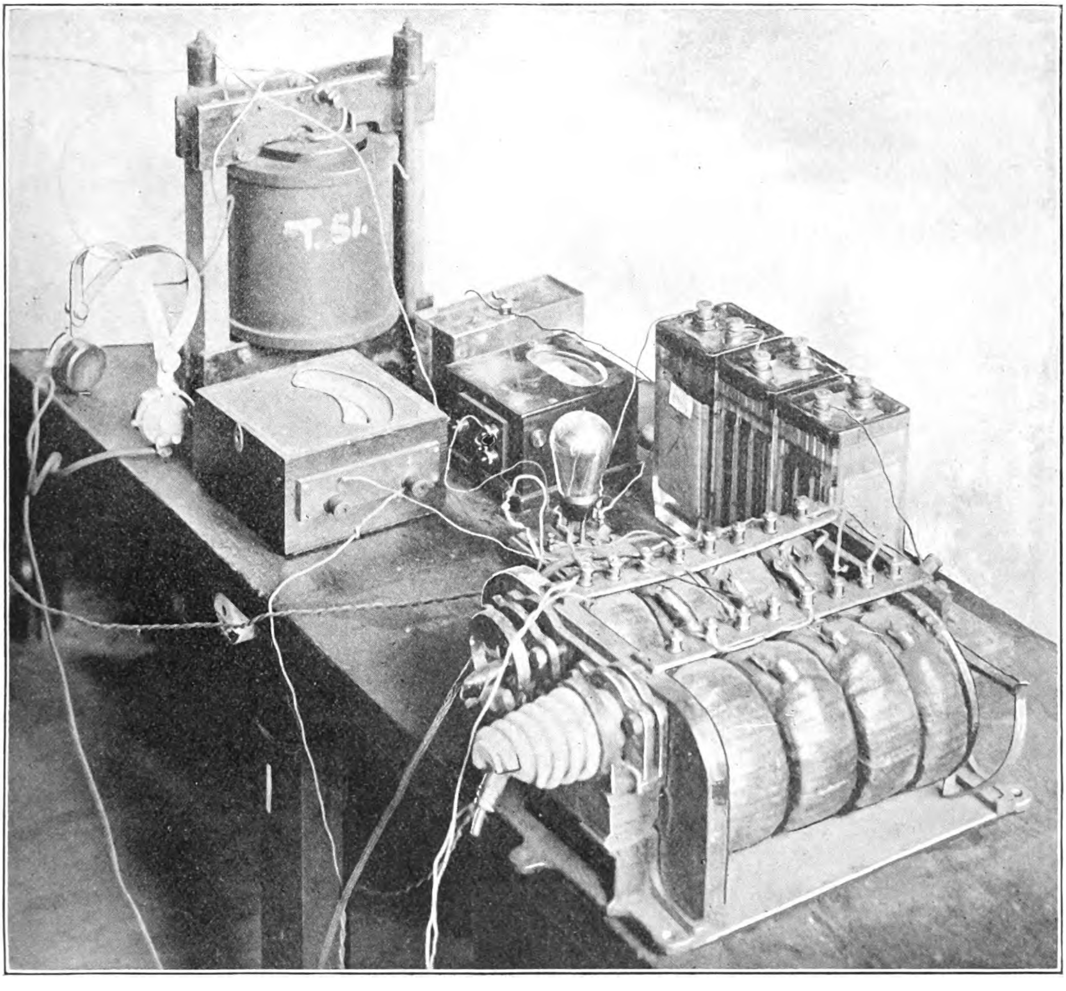


Fig. 8. *Transformers and apparatus for maintaining tuning fork.*

transformer were arranged to give the highest ratio, viz., 14 to 1.

With this arrangement and using a D.E.5B. Marconi valve having relatively small value of the ratio R_0/μ, the increase of anode current when fork was maintained was from 0.7mA to 2.7mA with 180 volts on the anode and a grid bias of 6 volts. The value of grid bias was found to be quite critical. At zero bias the fork would not maintain at all.

VI. Determination of Frequency of Maintained Vibrations.

The fork now maintaining well, the question arises as to how best to determine its frequency.

It was proposed to synchronise a small phonic motor with the fork, taking power from the fork circuit through a two-stage amplifier. For efficiency in supply of power our design must be such as to match the impedance of the motor with the last stage of the amplifier. After careful design the motor was wound to have as high an impedance as was practically possible, this amounting to about 2,500 ohms at 128 cycles. To match this the last stage consisted of two Western Electric 216A valves in parallel. across the transformer winding in the anode circuit of the valve maintaining the fork. It was essential to eliminate grid current as far as possible so that the conditions in the fork circuit were not changed.

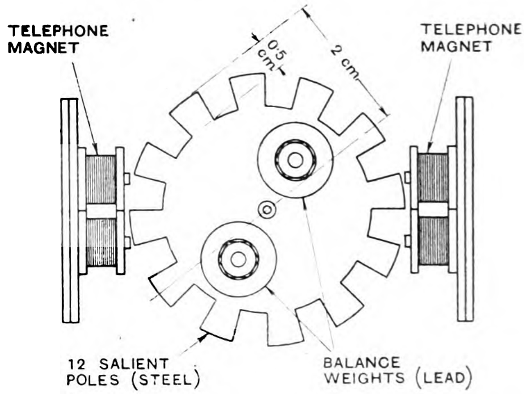


Fig. 10. *Diagram of synchronous motor.*

After various trials to synchronise the motor with the fork, all of which were unsuccessful, it was decided that in all probability the amplifiers were unable to supply a large enough voltage to run the motor at this frequency of 128 cycles. Tests were

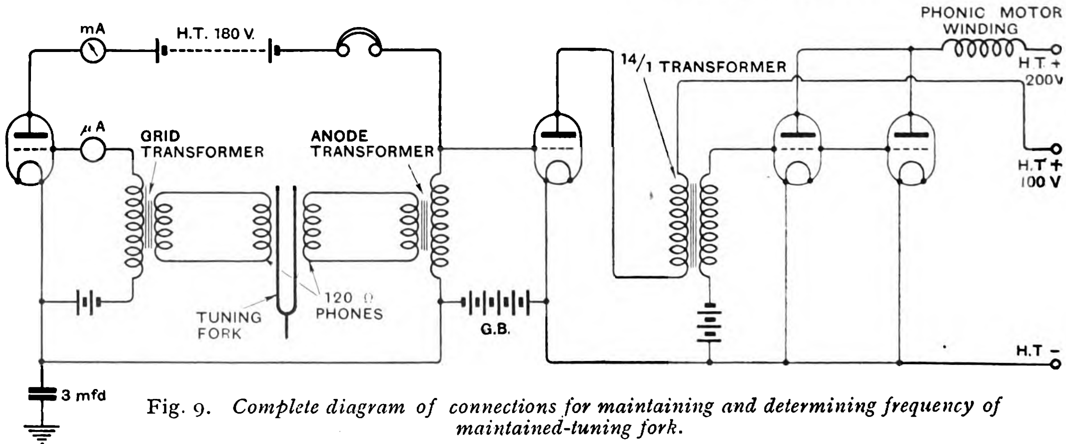


Fig. 9. *Complete diagram of connections for maintaining and determining frequency of maintained-tuning fork.*

The output from the fork circuit was taken direct across the transformer winding which is in the anode circuit of the maintaining valve. The diagram of connections is given in Fig. 9.

The first stage of amplification was performed by a Cossor "Stentor 6" super power valve the input to the valve being taken made on the motor using a variable A.C. supply and it was found that 150 volts A.C. output would be required to run the motor at the 128-cycle frequency. A very much smaller motor was, therefore, tried and this was found to pull into step with a 25-volt 128-cycles A.C. supply. This was evidently more suitable and was finally adopted. A

view of the motor is given in Fig. 11, which also shows the starting gear and counting train. The motor consisted of a balanced wheel of mild steel with 12 salient-poles on a long steel spindle which we will call "*a*". located below the counting train. The D.C. motor, also shown in the picture, is a 6-volt starting motor with a series winding, and a series resistance seen on the left of the box for speed control. This motor drives

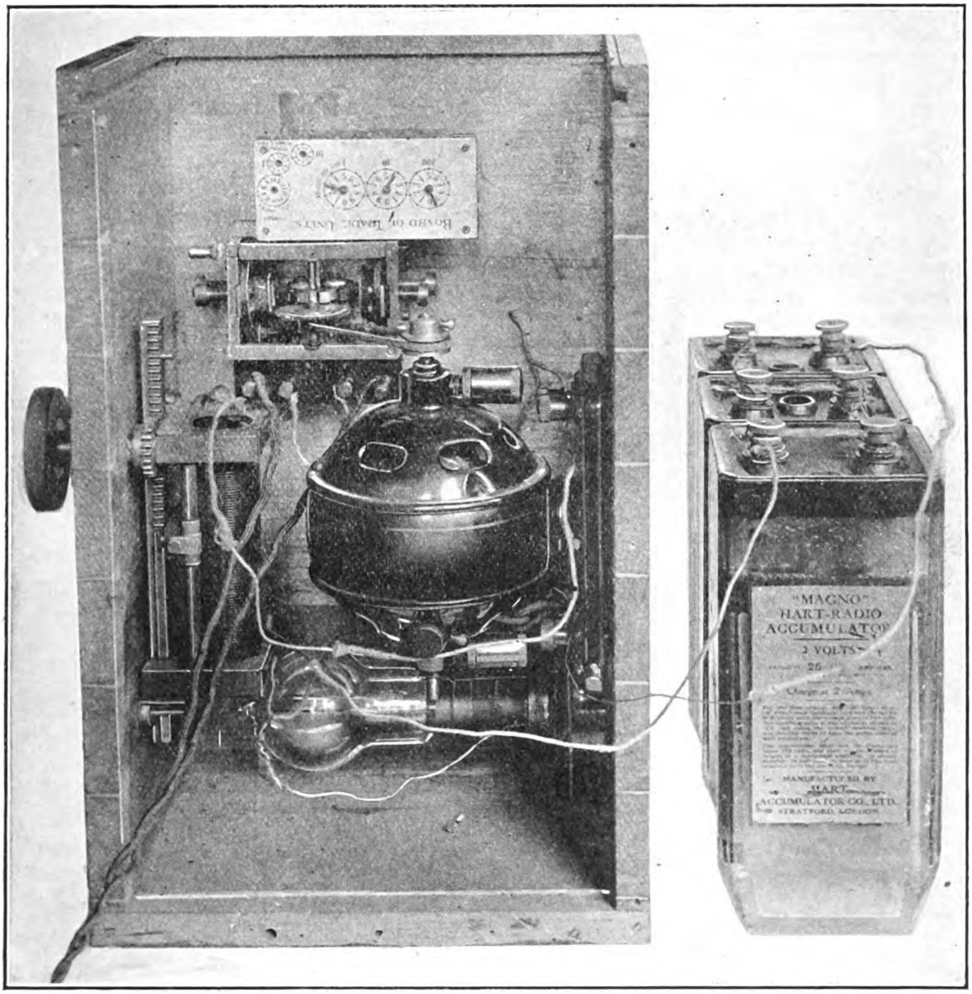


Fig. 11. *View of phonic motor, starting gear and counting train.*

Two old telephones were used as driving coils, being connected in series in the correct direction and being situated so that there was a very small air gap between the poles of the motor and the phone magnets (see Fig. 10).

In the photograph in Fig. 11 the poles of the motor can be seen just above the cog wheel within the brass rectangle which is directly by a belt on the spindle "*b*" with the large cog, seen in the brass rectangle. The top bar of the rectangle is a lever pivoted about its right end, which presses the spindle "*b*" downwards against a spring and engages the cog on spindle "*b*" with a cog on spindle "*a*". The latter cog has a free wheel so that the phonic motor can pull into step even though the starting motor

has exceeded the synchronising speed. This freewheel was not found to be successful, however, and it is a feature with these motors that the speed has to be adjusted very carefully before they will pull into step; speeding the motor up and allowing to slow down through synchronous speed is not very effective. When synchronised the releasing of the pivoted lever disengages the cogs and the starting motor can be stopped leaving the phonic motor running in synchronism with the maintained fork. At the top of the long spindle "*a*" on the phonic motor is a small cog which engages with a counting train and the dials are thus made to record to a known reduced scale the number of vibrations of the fork. At the bottom of the box is a Neon lamp which, if connected to the phonic motor supply, indicates by a stroboscopic effect when the wheel is running synchronously. The wheel is looked at from above the box and the glow of the Neon lamp is visible below it through the poles of the wheel; at synchronism the wheel appears to be stationary against the glow of the lamp. As the power supply was so limited in the present case the Neon lamp was disconnected and the wheel synchronised by trial.

This type of phonic motor was found to be quite suitable for its purpose of determining the frequency of the maintained fork. With practice synchronising the motor became an easy task. The motor was run for a considerable period of time extending over a number of hours and measured accurately by a chronometer, and the dials of the counting train recorded a number which when divided by a factor :—

$$[15 \times \text{Period of Trial (Hours)}]$$

gave the accurate frequency of the maintained fork.

Thus not only have we a constant frequency source but in addition we know the actual value of this frequency to many places of decimals and we are now ready for any experiment which calls for comparison of one unknown frequency with that of a standard known source. If the harmonics of this known frequency are amplified by some device, such as a multivibrator, we have a comparison standard of a range extending from the audio frequencies up to radio frequencies.

The Performance of Reflexed Valves.

By D. Kingsbury.

WHEN recently testing the relative performance of two audio-frequency intervalve transformers in a reflex receiver, the writer noticed certain peculiarities in the results obtained which called for further investigation. The conclusions reached are, to the best of his knowledge, novel and are therefore offered in the hope that they may be interesting to others.

The circuit of the receiver, a "one-valver," is shown in Fig. 1, from which it will be noted that R.F. step-up transformers with tuned secondaries are used in both the grid and anode circuits of the valve. A third winding, having the same number of turns as the primary, has been placed between the primary and secondary of the anode transformer and is arranged to perform three functions simultaneously :—

1. To provide R.F. stabilising E.M.F. ;
2. To balance out the A.F. component of the valve output within the transformer; and
3. To provide an earth screen between primary and secondary to A.F. voltages.

The object of functions (2) and (3) is to prevent the transfer of A.F. energy to the detector circuit and is attained with the connections shown. The remainder of the circuit represents standard practice.

The set was adjusted to absolute stability before the commencement of operations. By absolute stability is meant that, without the use of magnetic reaction, produced by moving the second R.F. transformer away from the normal 55 degrees from the horizontal, it is not possible to produce oscillation even with the aerial disconnected and the contact wire removed from the crystal. Further, with the aerial connected but with the crystal disconnected, it is not possible to hear the local station although the same is more than pleasantly loud on a horn type loud-speaker when the crystal is restored to service. The subject of stability in reflex receivers has been dealt with by the author elsewhere* and it will suffice to say in passing that unless a high degree of stability is obtained such investigations as those about to be described, where A.F. transformers are changed and their connections reversed indiscriminately without sensible alteration to the R.F. portion of the circuit, are practically impossible.

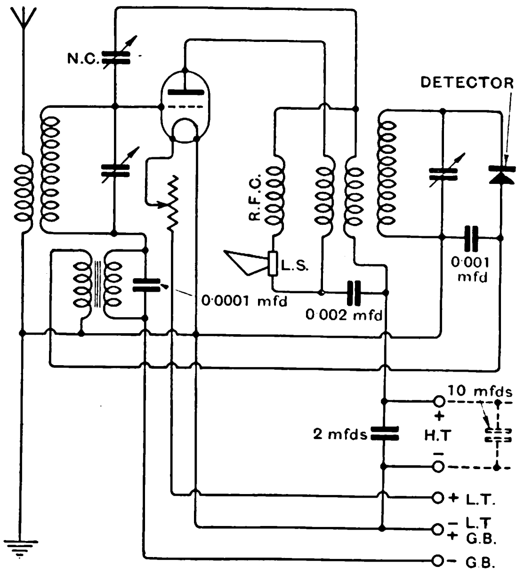


Fig. 1.

The two transformers under test were an R.I. 4 : 1 and a Marconi Ideal 6 : 1 which differ widely in construction and tonal characteristics. Two valves were used in turn, a Burndept L525 and a Marconi Osram D.E.5, the former having a somewhat lower impedance, lower self-capacity and longer "straight" than the latter. The anode volts in both cases ranged from 130-200 and the grid bias from $-4\frac{1}{2}$ to $-13\frac{1}{2}$ in steps of $1\frac{1}{2}$ volts. Two different loud-speakers, one horn type and the other diaphragm type, were also employed.

The foregoing details have been given to dispel at the outset any suggestion that the following reasoning is based on the peculiarities of one particular piece of apparatus. Substitution made no essential difference to the effects observed.

In the first place it was noticed that with

* "Reflex Receivers," *Wireless World*, p. 21, 7th July, 1926.

either transformer a rough and slightly deeper tone was obtained with one set of connections than with another.

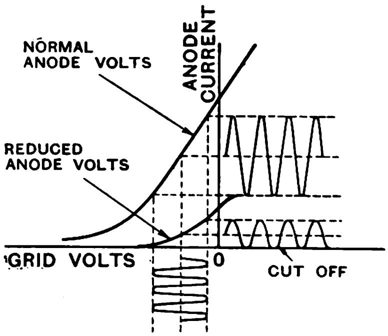
The arrangement of connections will be called "straight" and "crossed" for easy reference. In the case of the R.I. "straight" indicates I.P. to earth, O.P. to crystal contact wire, I.S. to grid and O.S. to bias battery, while with the Marconi "straight" indicates I.P. to earth, O.P. to crystal contact wire, O.S. to grid and I.S. to bias battery. The crossing of *either* primary *or* secondary corresponds to the arrangement called "crossed." (The crossing of both primary and secondary retains the original "straight" arrangement and effect.)

The "straight" connections gave the rough results; the Marconi being the louder, gave very rough results. This seemed to indicate valve distortion, but it was not possible to cure the trouble within the safe limits of voltage for the valves in use. It was noticed that if the filament current was decreased slowly, tone steadily improved up to a point at which signals were fast disappearing. Further, on switching off the rectifier which supplies the anode current from A.C. mains and which has about 12μF shunted across its output terminals a howl similar in pitch to the parasitic roughness was heard from the loud-speaker as the voltage collapsed.

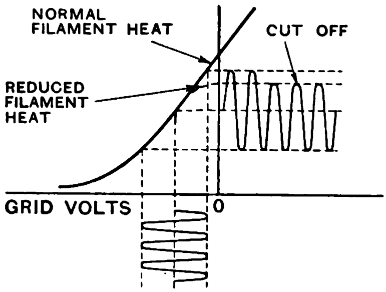
The "crossed" connections gave smooth and eminently satisfactory results on both transformers, but it was noticed that the roughness and howl mentioned above now appeared as the filament was slowly dimmed and that when switching off the rectifier the music died a natural death.

The effects on the output of the valve of reducing anode volts and reducing filament current can perhaps best be appreciated by examining the typical valve characteristic curves shown in Fig. 2. Fig. 2(a) indicates that the negative half cycles suffer first if the anode voltage be gradually reduced and from Fig. 2B we see that the reverse is the case if the filament be dimmed.

Now the essential difference between the "straight" and "crossed" connections is the reversal of polarity of the A.F. impulses applied to the grid of the valve in respect to the modulations in the incoming R.F. wave, and since a suppression of the negative half cycle of the composite input wave (by reducing the anode volts) causes a howl with the "straight" connections while a suppression of the positive half cycles (by reducing filament current) causes the same howl with "crossed" connections, we are led to the conclusion that the input to the



(a)



(b)

Fig. 2.

valve is asymmetrical and that only one half-cycle is markedly susceptible to curvature in the valve characteristic.

Let us, therefore, consider in detail the conditions under which the valve has to operate. Fig. 3(a) represents C.W. modulated by a simple note and will be taken as representing the R.F. input. Now this input is amplified and passed on to the crystal for rectification after which it is reapplied to the valve grid by means of an A.F. transformer. In relation to the modulation in the input wave, the voltage wave occurring at the terminals of the secondary of the A.F. transformer may be in the form of 3(b) or 3(c). 3(b) has a positive maximum when the R.F. input is greatest whilst 3(c) has a positive maximum when the R.F. input is at a minimum. Just exactly which wave we do

obtain depends on at least three factors:—

1. The R.F. transformer connections;
2. The crystal connections;
3. The A.F. transformer connections.

There is a further factor, namely, transformer phase shift which is assumed not to be

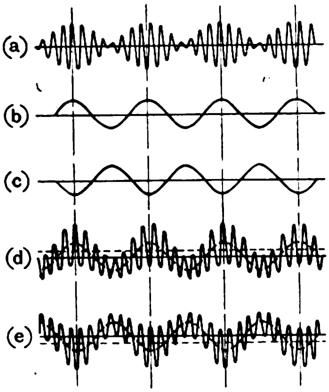


Fig. 3.

of sufficient magnitude under the present circumstances to warrant consideration since the frequency (*i.e.*, pitch) of the phenomenon does not vary greatly with any given transformer.

If we combine the A.F. waves 3(b) and 3(c) in turn with the R.F. wave 3(d) we shall obtain waves 3(d) and 3(e) which show quite clearly that asymmetry does exist. In the case of 3(d), since the amplitude of R.F. wave is a maximum during the positive half-cycle of the A.F. wave and a minimum during the negative half-cycle, the mean of the combined wave (dotted line) is positive in respect to the mean of the basic A.F. or R.F. waves (full line). The opposite occurs with the wave 3(e) where the mean of the combined wave is negative in respect to the basic waves.

Fig. 4 shows the case of 3(e) supplied to a valve, and the main point to be noted is that the valve is no longer working at the mean potential applied by the bias battery. This gives us a clue as to how to find out whether this curve is produced with the "straight" or the "crossed" connections. If we suddenly short-circuit the A.F. transformer secondary while signals are being received, there should be, under the conditions depicted in Fig. 4, a rise in anode current. This actually occurs with "crossed" connections the reverse (a fall in current) happening with the "straight" arrangement. Now since a howl takes place on reducing the filament current with "crossed" connections (see Figs. 2(b), 3(e) and 4) and also occurs on reducing the anode volts with "straight" connections (Figs. 2(a) and 3(d) we may draw our second conclusion, viz., that the particular howl and roughness only occur when valve characteristic curvature is allowed to interfere with the lesser half-cycle of the composite wave, *i.e.*, that period during which the R.F. wave is most depressed by the modulation of the transmission.

And so to the inevitable "Why?" Fortunately the characteristic howl can be produced with the "crossed" connections on the unmodulated carrier of the local station (providing a really excellent spot on the crystal be obtained) if the filament be slowly dimmed. No effect is obtained when mistuned or when the station is shut down. This makes examination of the subject simpler and we will proceed with the case of filament dimming.

In order fully to understand the "mechanics" underlying this phenomenon

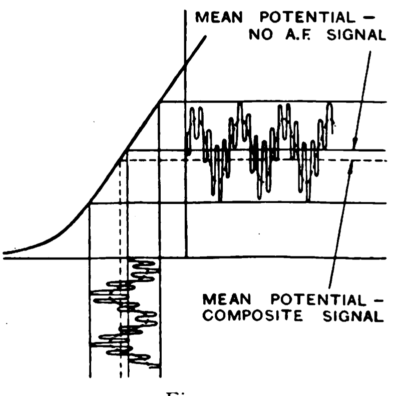


Fig. 4.

it is necessary to bear two facts in mind: Firstly, that on the input side of the valve there is an A.F. transformer secondary between the R.F. transformer and the bias battery, instantaneous positive or negative potential from which will carry the R.F. wave bodily higher up or lower down the characteristic curve of the valve than the region we choose when setting the bias battery and secondly, that filament dimming lowers the upper limit of the useful part of the valve characteristic curve.

Consider now normal conditions when receiving the unmodulating carrier of a broadcast station. The R.F. wave is being applied to the grid of the valve, which, after amplification passes it on to the crystal. The crystal, by reason of its unilateral conductivity and the blocking condenser, passes a steady current through the A.F. transformer primary. Because this current is steady no voltage is generated in the transformer secondary.

We then modify these conditions by dimming the filament which has the effect, already described, of reducing the R.F. output of the valve owing to partial cut off of the positive half-cycles (see Fig. 2(a)). Now this reduction in R.F. output is accompanied by a reduction in steady current passing through the transformer primary which causes a momentary positive potential from the secondary in accordance with our previous findings for " crossed " connections (see Figs. 3(a), 3(c), 3(e) and 4). But this momentary positive potential from the transformer secondary carries the whole R.F. wave further up the characteristic curve of the valve, the upper limit of which has been fixed by the reduction in filament current and so further suppression of the positive half-cycles takes place and therefore a still greater reduction in the steady current in the transformer primary and therefore further positive potential from the secondary which in turn causes still more cut off. A state of change, tending towards the complete extinction of the positive half-cycles of R.F. wave exists, which change obviously cannot continue indefinitely and so the positive potential being generated in the A.F. transformer secondary commences to die away.

As soon as this happens, however, the R.F. wave is allowed to move down the curve and the cut off becomes less severe. This allows an increase in the rectified current which is accompanied by a negative potential across the A.F. transformer secondary terminals. This negative potential will carry the R.F. wave down the characteristic curve tending to allow it to grow to its normal value (*i.e.*, that value obtaining before we reduced the filament current).

Again this condition cannot last indefinitely and the negative potential commences to die away so that conditions eventually become as they were when we had first dimmed the filament. This cycle will be repeated continuously, in fact, the arrangement is unstable and oscillates at a frequency depending almost wholly upon the constants of the A.F. transformer and the magnitude of the R.F. wave. Fig. 5 is an attempt to show the state of affairs.

Following the same reasoning for the filament dimming case with " straight " connections (wave 3D) it will be seen that a reduction of the R.F. wave " cut off " produces a negative voltage from the transformer which tends to enlarge the R.F. wave to its former value at once and thus limits the generated A.F. voltage. Stable conditions are thus assured. Exactly the same argument holds good for the opposite cases of reduced H.T. voltages.

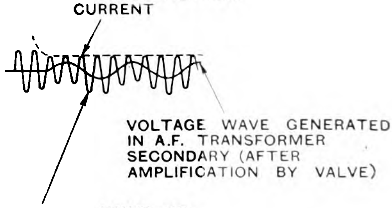


Fig. 5.

Our third conclusion is, therefore, that in order to ensure freedom from parasitic howls and A.F. reaction effects, it is necessary to provide a good straight portion of the valve characteristic for the lesser half-cycles of the incoming R.F. and A.F. wave previously shown to be asymmetric. A curvature in that part of the characteristic on which the greater half of the wave operates may actually be an advantage as it tends to limit the loudest notes only, although introducing slight even harmonics which the author has not yet been able to recognise aurally. These results are best obtained by working under the conditions shown in Fig. 4 (which give an increase in anode current if the A.F. transformer secondary is suddenly shorted while receiving broadcast) and if necessary by decreasing the H.T. voltage slightly whilst retaining adequate filament heat and grid bias.

Somewhat insufficient negative grid bias will produce the howl already observed owing to partial suppression of the R.F.

wave by grid current but the effect is different as only notes above a certain intensity are affected. With much too little or no grid bias it is not possible to produce the note, presumably owing to heavy damping, also it is not possible to demonstrate the effect with a feeble R.F. input, in fact the author has come to consider the phenomenon as indicative of a healthy set and suitable operating conditions.

Having established the cause of his howl let us give it a name. It is, of course, a species of A.F. reaction but the author proposes to call it the reflex interference note to distinguish it from true R.F. or A.F. oscillation, which are quite different both in cause and effect.

The reflex interference note is—like mechanical friction, electrical resistance, etc.—at first sight highly undesirable but really quite useful. We may set the crystal with it by firstly tuning the local station to the greatest apparent loudness, then tuning the filament down to the point at which a sharp decline in anode current sets in and then trying a number of places on the crystal. Some spots will produce no note, others a mediocre and erratic note while a few will produce quite a loud, steady and rather low pitched note; these are the good spots. We may very fairly judge the merits of a crystal by the number of good notes we obtain out of, say, twelve contacts. Similarly, we have a crude but useful way of indicating if the crystal is ageing.

One may tune the local station the absolute maximum loudness with this interference phenomenon. Having obtained a good spot of the crystal with its aid, a slight adjustment of both anode and grid condensers may increase the loudness of the note and in this respect tuning is quite sharp.

The relative suitability of valves for the circuit may be quickly estimated by seeing which produces the loudest note and the comparative excellence of two valves of the same type but different manufacture may similarly be estimated. The author has found that there are appreciable differences in this direction, probably due to the better bases used by some makers.

The note gives audible indication should the L.T. accumulator fail while in use; a useful point. In the same way failure of emission of a valve has on two occasions been shown up.

The question as to how many volts negative grid bias are required can be answered quite easily by listening for traces of the interference and in this connection it is remarkable what a large swing is produced by the low notes of the piano and harp and by certain drums.

The author has tried some six different A.F. transformers in the set and found that the pitch of the note is different for each transformer, and the lower the note, the better the transformer is on music, provided the loud-speaker in use is capable of dealing with low notes. The now famous "nearly perfect" transformer (Ferranti) gives an interference note estimated at 150 cycles. The smaller of the two transformers mentioned at the beginning of this article gave a note estimated at 1,500 cycles. A small French transformer tested as a matter of interest either could not muster enough output to produce a note or the note was above audible frequency (it was *not* sold to the author as a supersonic instrument).

Loading a transformer with by-pass condensers makes a slight difference to the note, but not so much as is obtained between two transformers of different makes.

Finally, a word in support of the reflex set. It should be noted that the roughness which gave rise to these investigations only occurred when obtaining loud-speaker strength at nine miles from 2LO without a trace of reaction. Further, as has been shown, this roughness is curable until the limit of the valve has been reached. In the author's opinion far too little serious thought has been applied to this class of receiver with the result that its reputation is anything but good. Only the other day his attention was drawn to a circuit just published and announced as likely to have an important bearing in reflex design in the future. The first glance showed a variable condenser consisting of two $.0005\mu F$ sections so connected that amongst other things it shunted the *secondary* of the associated A.F. transformer. In other words, anything up to $.001\mu F$ was applied at a point where $.0001\mu F$ is by design and selection* ample and from the point of view of quality possibly too much.

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* "Bypass Condensers in Reflex Receivers," by D. Kingsbury, *Wireless World*, 20th October, 1926, pp. 546-550.

Grid Signal Characteristics and other Aids to the Numerical Solution of Grid Rectification Problems.

By W. A. Barclay, M.A.

(*Continued from page* 466 *of August issue.*)

Part II.

In the previous part of this paper we considered the derivation and use of certain curves obtained from the grid current characteristic of a valve, to which the writer gave the name of *grid signal characteristics*, and an example was given of the use to which such curves may be put in determining the mean voltage on the grid during the rectification of a C.W. signal. The method of use was shown to be analogous to that employed in the determination of the initial conditions from the ordinary characteristic. The *raison d'être* of the grid signal characteristics being thus established, we shall now proceed to consider a means whereby, in the majority

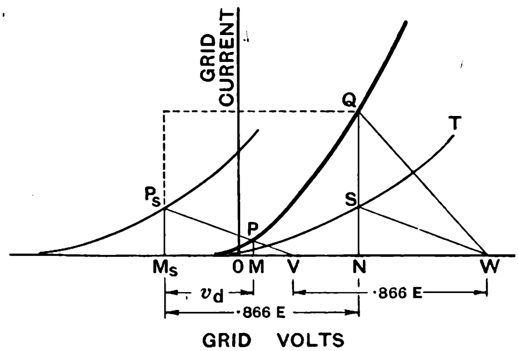


Fig. 7. *Method of deriving mean grid signal voltage from the original characteristic. The length* M_sM *represents* u_d, *the grid voltage shift owing to rectification.*

of practical cases, the actual drawing of these curves is rendered unnecessary and may be dispensed with. It will further appear that in these cases the required values of mean grid voltage during signal reception may be ascertained directly from the original characteristic.

In the diagram of Fig. 7, let the curve *PQ* denote the grid current characteristic, whose equation, when referred to suitable axes, may be written—

$$i_g = f(v_g)$$

Let *ST* be the curve whose ordinates are one-third those of *PQ*, its equation being—

$$i = \tfrac{1}{3}f(v_g)$$

Take the point *V* to represent the value v of grid voltage, and let *VP* be the slope line for resistance *R* and bias voltage v. Then *M*, the projection of *P* on the voltage axis, represents the pre-signal voltage of the combination. We have seen that the grid signal characteristic of amplitude *E* is, for all that part of the diagram in which the ordinates of *PQ* are negligible, a replica of the curve *ST*, transferred horizontally to the left through a distance of $.866E$ along the voltage axis. This curve having been drawn in, let P_s be the point of its intersection with the leak line *VP*. Then the required value of mean grid voltage during the passage of the signal is given by the abscissa of P_s, represented by the point M_s.

Let us now consider an alternative method of finding M_s. Take a point *W* on the voltage axis at a value $v+.866E$, and through it draw a line parallel to *VP* to meet the curve *ST* in *S*. Then, since the two curves are horizontally apart by $.866E$, the parallel lines VP_s and *WS*, also at the same horizontal distance apart, will meet them in the two points P_s and *S*, whose ordinates M_sP_s and *NS* are equal, and whose distance apart is also $.866E$. But—

$$P_sS = M_sN$$

Therefore—

$$M_sN = .866E \text{ volts,}$$

so that the point M_s may be found by setting off this distance to the left of *N*. Having obtained *N* by means of the gradient line *WS* and the curve *ST*, the value of v_s is found by subtracting $.866E$ from the value of the voltage represented by *N*.

Consider, further, the derivation of the point *N*. The ordinates of the curve *ST* being one-third those of *PQ*, it will be

obvious that a line through W, whose gradient is three times that of WS, will meet the original characteristic PQ in a point Q whose abscissa will be the same as that of S. It will not be necessary, therefore, even to draw the curve ST. *The original characteristic may be made to serve,* provided the line WQ used to intersect it have three times the gradient of WS, *i.e.*, of VP, and that it pass through a grid voltage point W representing a value equal to $v+.866E$. The gradient of the slope line WQ will therefore be that corresponding to a leak resistance of one-third the value of the given leak R, and is thus easily plotted. As already stated, there falls to be deducted from the value of grid voltage found at N the amount $.866E$, in order to obtain the required value of mean grid voltage during signal reception.

We may now shortly summarise the procedure to which we have been conducted. To obtain the mean grid voltage during the rectification of a signal of amplitude E with a leak resistance R and fixed bias voltage v we have the simple rule :—

From a point on the voltage axis situated at $v+.866E$, draw a line of gradient corresponding to a leak of $R/3$. From the intersection of this line with the curve measure back $.866E$ volts. The resulting voltage is that of the grid under the signal conditions; subject to its position being on that part of the diagram for which the original characteristic has zero ordinates.

(If the mean voltage under signal conditions is not on this part of the diagram, recourse must be had to the actual plotting of the signal characteristics as previously described.)

An interesting verification of this procedure is shown in Fig. 8. The grid characteristic there given is the exponential curve found by Mr. Colebrook for an Ediswan dull-emitter valve.* When plotted to a suitable scale, reckoning in microamperes and volts, its equation may be written

$$i_g = 3.16\epsilon^{5.55v_g}$$

With a leak resistance of 1.89 megohms and zero bias voltage, Mr. Colebrook finds the initial voltage on the grid to be —.461.

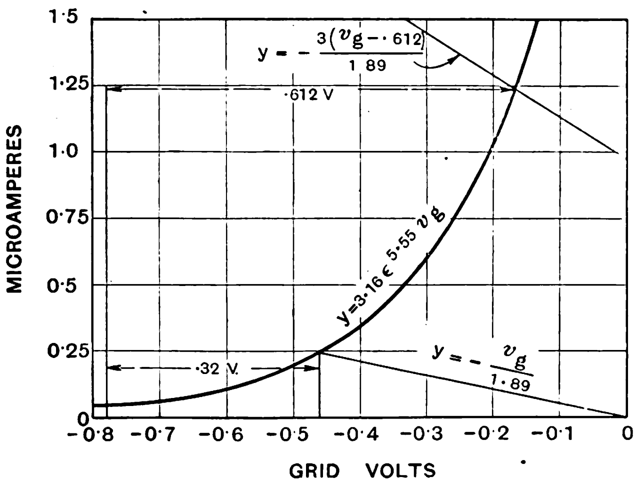


Fig. 8. *Exponential grid current characteristic.*

This value is, of course, the abscissa of the intersection of the curve with the line whose equation is

$$i_g = -\frac{v_g}{1.89}$$

which is the lower line plotted on the diagram.

Assuming now a signal amplitude of .707 volt, he proceeds to calculate, by means of curves applicable to the exponential form of characteristic, a mean change of grid potential equal to .329 volt. (In passing, it should be remarked that accuracy of this order is entirely contingent upon the degree of approximation of the characteristic to the assumed exponential form. In this case, of course, the assumption of this form is explicitly made, and there is no limit,

* See *E.W. & W.E.*, Nov., 1925, p. 871.

theoretically, to the accuracy obtainable under this hypothesis.)

On our diagram (Fig. 8) the upper resistance line has been drawn in accordance with the preceding rule to intersect the voltage axis at the value $O+(.866\times.707)$ volts, while having a gradient three times that of the other line. Its equation will therefore be

$$i_g = -\frac{3(v_g - .612)}{1.89}$$

from which it may be readily plotted.

On setting back a distance corresponding to .612 volt from the abscissa of the new intersection, we obtain —.78 as the value of mean grid voltage during the signal, corresponding to a change of .32 volt. A useful check is thus afforded on the accuracy of the new method, which, it is to be remembered, is applicable with equal ease to other forms of characteristic besides the exponential.

It might be anticipated that in the above simple construction for the derivation of the mean grid voltage change in signal reception, the subject had, from the computer's point of view, been "reduced to its lowest terms." This, however, is not the case, and the writer believes that an account of a device which he has elaborated to simplify yet further such calculations will be found of service to many experimenters interested in the statistics of grid detection. Especially will the device be useful where many such calculations are required to be done in bulk, *e.g.*, when it is desired to study the effect of varying any particular factor, such, for instance, as signal amplitude or leak resistance.

The foundation of the method consists in the use of semi-logarithmically ruled paper, the utility of which to the serious experimenter, though little known, can scarcely be over-estimated. This paper, which can be obtained very reasonably from several scientific instrument makers, is graduated logarithmically along one axis only, the other being divided at equal intervals in the usual way. It is a simple matter to replot the i_g—v_g characteristic curve upon such paper, taking values of i_g upon the logarithmic and v_g upon the linear axis. The values of grid current, as is known, increase rapidly with positive grid voltage, and for this reason the logarithmic paper will show them more conveniently than the ordinary diagram. For negative values of grid voltage, the grid current becomes negligible in comparison with its higher values, so that we may stop our representation of it when it falls below, say, .2μA. Such a representation of a grid current characteristic is shown in Fig. 9, in which the horizontal axis is divided to represent integral values (both positive and negative) of grid potential in volts while the vertical axis is graduated logarithmically to represent positive values of grid current from .2 to 20μA. The characteristic shown is a portion of that of the Edison D.R.2 valve previously illustrated at Fig. 5.

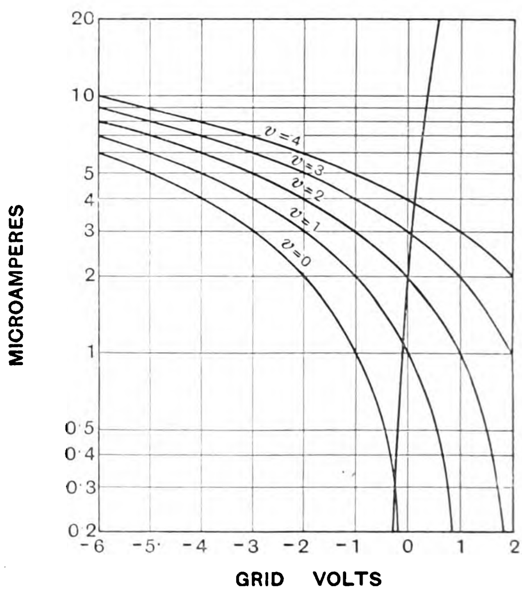


Fig. 9. *Logarithmic grid characteristic diagram, with portion of Edison D.R.2 characteristic.*

We now develop the diagram by plotting in a series of curves which are to represent various values of fixed bias voltage v. The law of their construction will become apparent from the following examples: For the curve representing $v=0$, we join all the points the algebraic sum of whose co-ordinates (expressed in the units, volts and μA) is zero. Thus, the points ($v_g=-2$, $i_g=2$) and ($v_g=-0.5$, $i_g=0.5$) will lie on this curve. For the curve $v=1$, we join all points the algebraic sum of whose co-ordinates is 1, and similarly for the other values of v, integral or fractional, in which we are interested. In the diagram of Fig. 9, these curves are shown for steps of 1 volt from $v=0$ upwards. They will

be found exceedingly simple to construct upon the ruled network, as their course is marked by the intersections of vertical and horizontal lines already ruled upon the diagram throughout their length. In practice —owing to the decimal graduation of the logarithmic paper—sub-divisions of $\frac{1}{10}$ volt in v are readily drawn in.

Finally, prepare a cursor cut from stiff paper in the form of a **T** as shown in Fig. 10. The head of the **T** is graduated logarithmically to the same scale as used in the diagram of Fig. 9, from which the markings may be readily copied. These graduations are to represent values of leak resistance, measured

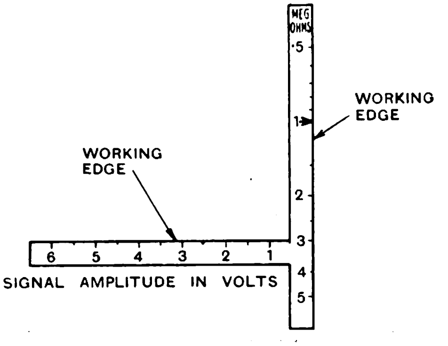


Fig. 10. *Cursor for use with Fig. 9.*

in megohms, the graduation for 1 megohm being distinguished by an arrow-head. Perpendicular to this scale, and forming the stem of the **T**, is a scale of signal amplitudes which meets the scale of resistance at the value 3 megohms. This scale is linear, the graduations being at .866 of the distances between the vertical voltage lines of Fig. 9 and are measured from a zero on the resistance scale. In applying the cursor to the diagram, it is to be oriented as shown in Fig. 10; the **T** is to be placed on its side, the stem being always kept horizontal and to the left of the head. The logarithmic graduations for leak resistance should then run in the opposite sense to that of the current graduations on Fig. 9.

The method of using the cursor on the diagram is twofold, solving the double problem of obtaining mean grid voltages (*a*) before, and (*b*) during signal reception. In both cases, the cursor is placed so that the resistance scale is parallel to the vertical lines on the diagram, while the graduation corresponding to the leak resistance in use is placed over the characteristic curve. The cursor is now at liberty to slide in this position along the characteristic.

(*a*) For pre-signal conditions, slide the cursor thus until the arrow-head is on the curve corresponding to the required value of v, interpolating by eye where this is necessary. The initial grid voltage is then read from the diagram at the position occupied by the resistance scale.

(*b*) For signal conditions, still keeping the resistance graduation upon the characteristic, slide the cursor until the signal amplitude graduation is over the same v curve. The voltage read from the diagram *at this point* is now the mean grid voltage during reception of the signal.

It thus appears that by two applications of the cursor to our logarithmic characteristic we can obtain immediately the mean grid voltages both before and during signals and this for any signal amplitude and using any desired values of leak resistance and bias voltage. The advantages obtained by the use of this simple device are obvious. The diagram of Fig. 9 with its network of lines and v-curves is available for use with any grid characteristic, and need not, therefore, be redrawn in order to contrast the detecting performance of different valves. The widest facility is also afforded for comparing results using different or varying values of the circuit constants concerned without either calculation or graphical construction. In particular, the applicability of the method to every grid characteristic, irrespective of its mathematical form, should commend it to the attention of the computer.

The limitations imposed on the method are the same as those implied in the method previously derived for use with the ordinary characteristic, *i.e.*, the value found for the mean signal voltage on the grid must be such that the corresponding grid current is negligible in comparison with other values to which this current may attain during the cycle of oscillation. This, in effect, precludes the use of the method for very small amplitudes of signal voltage, as with these the current corresponding to the mean voltage of the grid tends to become equal to the mean value of the total current during the oscillation. In these cases, as already remarked, recourse to the grid signal characteristic curves becomes necessary.

A short mathematical proof of the properties of the logarithmic characteristic and cursor will now be given. Referring to the diagram of Fig. 7 in which suitable units of length were taken on the axes to represent volts and microamperes, we saw that if the original grid characteristic has the equation

$$i=f(v_g) \quad \dots \quad \dots \quad (14)$$

the curve ST has the equation

$$i=\tfrac{1}{3}f(v_g) \quad \dots \quad \dots \quad (15)$$

while the grid signal characteristic of amplitude E has the equation

$$i=\tfrac{1}{3}f(v_g+.866E) \quad \dots \quad (16)$$

Using a grid bias of v volts and a leak of R megohms, the equation of the line VP is

$$i=\frac{v-v_g}{R} \quad \dots \quad \dots \quad (17)$$

If v_0 denotes as usual the pre-signal voltage on the grid, while v_s denotes the mean grid voltage during the signal, the values of v_0 and v_s may be determined as the result of eliminating i between (14) and (17), and between (16) and (17) respectively. Hence v_0 is the solution of

$$f(v_g)=\frac{v-v_g}{R} \quad \dots \quad \dots \quad (18)$$

considered as an equation in v_g, while v_s is the solution of

$$\tfrac{1}{3}f(v_g+.866E)=\frac{v-v_g}{R} \quad \dots \quad (19)$$

similarly considered.

In the logarithmic diagram, Fig. 9, let the axes of co-ordinates be the horizontal line representing $1\mu A$, and the vertical representing zero grid volts. Choosing a suitable scale for representation along each of these axes, we may write the equation of the characteristic as now plotted,

$$y=\log i=\log f(v_g) \quad \dots \quad (20)$$

where y, the distance from the $1\mu A$. line, is to be reckoned positive or negative according as $f(v_g)$ is greater or less than $1\mu A$. With the same convention, we find that the equation to the family of curves representing grid bias voltage may be written

$$y=\log(v-v_g) \quad \dots \quad \dots \quad (21)$$

to each curve corresponding to its appropriate value of v.

If, now, the head of the cursor be slid over the characteristic, the graduation corresponding to R being always over the curve, the arrow-head at the value 1 megohm will obviously describe the curve

$$y=\log f(v_g)+\log R \quad \dots \quad (22)$$

When the arrow-head in its travel meets the desired v-curve, the value of v_g will then be obtained by eliminating y between equations (21) and (22), giving

$$\log(v-v_g)=\log f(v_g)+\log R \quad \dots \quad (23)$$

an equation which is seen to be identical with equation (18) already obtained for the determination of v_0, the initial grid voltage.

In finding v_s, the head of the cursor is again slid while maintaining the graduation for R over the characteristic. The zero of the signal amplitude scale, situated at the value 3 megohms on the head of the cursor, will then describe the curve

$$y=\log f(v_g)+\log R-\log 3 \quad \dots \quad (24)$$

Hence the graduation on the cursor corresponding to signal amplitude E, distant to the left of this zero point by $.866E$, will describe the curve

$$y=\log f(v_g+.866E)+\log R-\log 3 \quad (25)$$

When this graduation arrives over the v-curve of equation (21) the two values of y are equal. Equating them we have

$$\log(v-v_g)=\log f(v_g+.866E)+\log R-\log 3 \quad (26)$$

which, after rearrangement, is seen to be equivalent to equation (19) from which the grid signal voltage v_s is derived. Thus the construction is proved.

The logarithmic characteristic used in conjunction with the cursor as above described furnishes us (within the limits of its operation) with a convenient means of estimating the detecting performance of valves, a desideratum noticed at the outset of this paper. (It may be well here to remark that in speaking of "detecting efficiency" we are here confining ourselves solely to the grid circuit of the valve, and are ignoring the very importantly associated anode circuit.) In Fig. 11, let the right angles ABC and DEF represent the initial and final positions of the cursor. In the first of these the arrow-head (at 1 megohm) is on the curve $y=\log(v-v_g)$ while the point A, corresponding to resistance R, is on the characteristic. In this position the abscissa of the line AB is v_0, the initial

voltage. Substituting this value for v_g in the equation of the v-curve, we obtain for the ordinate of the arrow-head $log\,(v - v_0)$. Subtracting (algebraically) the distance equal to $log\ R$ between the arrow-head and the point A, we may write the co-ordinates of the latter $\{v_0, log\,(v - v_0) - log\,R\}$. In the position DEF, the point F on the horizontal stem of the cursor marks the graduation for signal amplitude E, which appears over the curve $y = log\,(v - v_g)$, the abscissa of the point being v_s. The ordinate of F may thus be written $log\,(v - v_s)$. At the same time the resistance graduation for leak R occupies

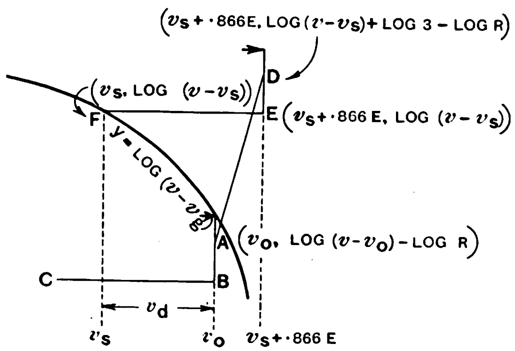


Fig. 11. *Showing dispositions of cursor upon the logarithmic diagram of Fig. 9.*

the position D on the characteristic. Since the point E, the zero of the scale of signal amplitude, is at a distance from F representing $.866E$ volts, the co-ordinates of E are $\{v_s + .866E, log\,(v - v_s)\}$, whence, again, those of D are

$$\{v_s + .866E, log\,(v - v_s) + log\,3 - log\,R\}.$$

The course of the characteristic is approximately shown by the straight line joining the points A and D. If the characteristic conforms to the exponential type, it will actually follow the line AD. For the usual type of rectifier valve, the course of the characteristic between working points such as A and D may be regarded as approximately linear. Whatever be the departure from the linear form, however, there will be a much smaller discrepancy between the slope of the line AD and the actual average gradient of the curve between these points. Indeed, we may in all cases regard the gradient of AD as a fairly accurate estimate of the average slope of the characteristic over the working range. If, then, we represent by G this average gradient, we have, from Fig. 11,

$$G = \frac{log\,(v - v_s) + log\,3 - log\,(v - v_0)}{v_s + .866E - v_0} \qquad (27)$$

If by v_d we represent the difference $v_0 - v_s$ between the initial and signal grid voltages, while by V we represent $v - v_0$ the initial potential difference across the leak, we may write :—

$$G = \frac{log\,3 + log\left(1 + \frac{v_d}{V}\right)}{.866E - v_d} \quad \ldots \quad (28)$$

Now it is obvious from Fig. 7 that, for all values of E suitable for the application of the method (*i.e.*, such that the current ordinate at resulting v_s is negligible), v_d will be less than $.866E$. Thus, for a given signal amplitude E, the value of G is seen to increase with increase of v_d, *i.e.*, other things being equal, *the greater the gradient of the logarithmic characteristic, the greater the rectifying efficiency of the grid circuit of the valve.*

It may be of interest to indicate a convenient means of correlating geometrically the magnitude of G with the other three variables of equation (28). Writing this in the form

$$G = \frac{log\,3 - \left\{-log\left(1 + \frac{v_d}{V}\right)\right\}}{.866\,E - v_d} \quad \ldots \quad (29)$$

it is seen that if on the diagram of Fig. 21 we take two points P and Q whose co-ordinates with respect to the cartesian axes OX and OY are

$$\{.866\,E,\ log\ 3\}$$

and

$$\left\{v_d, -log\left(1 + \frac{v_d}{V}\right)\right\}$$

the value of G will be represented by the gradient of the line PQ. All the points P are seen to lie along the horizontal line of ordinate equal to $log\,3$ in a linear scale of values of E. The positions of the Q points are determined by the values of the two variables v_d and V. The abscissa of each Q point is the corresponding value of v_d ; hence are drawn a series of vertical lines to represent that variable. The curves shown for V are then the result of eliminating v_d between the equations

$$x = v_d \text{ and } y = -log\left(1 + \frac{v_d}{V}\right)$$

i.e., they are the curves

$$y = -log\left(1 + \frac{x}{V}\right)$$

The position of any given Q point will thus be found at the intersection of its appropriate v_d line and V curve. If both the scales taken for the horizontal and vertical measurements in Fig. 12 are the same (or in the same proportion) as the corresponding scales in Fig. 9, the values obtained for G by means of the two diagrams will be identical. In Fig. 9 we are dealing with the actual values of grid bias, initial and signal grid voltages. In Fig. 12 we deal directly with the change of grid voltage due to the signal, and relate it to the pre-signal value of the P.D. across the leak V, the signal amplitude E, and the value of G. The two diagrams are thus complementary, but whereas Fig. 9 necessitates the use of the cursor described, Fig. 12 may be used as it stands.

To illustrate the use of Fig. 12, suppose the average value of G for the working portion of the logarithmic characteristic is known, and also the value V of the initial P.D. across the leak, then, by sliding a set-square so as to preserve the constant slope of gradient G, we can correlate values of E with the corresponding values of v_d, and this without reference to the actual values of grid bias and leak resistance. As the sliding edge of the set-square passes through successive values of E, it simultaneously intersects the given V curve at the required values of v_d. The $E-v_d$ characteristic of the valve may thus be readily graphed for various values of V for all except small values of E.

An interesting confirmation of Fig. 12 may be obtained by reference to the diagram of Fig. 6. On Fig. 12 the line PQ has been drawn of slope equal to the average of that of the logarithmic characteristic shown in Fig. 9, the signal amplitude E being taken as 2 volts. From Fig. 6, which shows the original and signal characteristics of the same valve, it is seen that for a leak of 1 megohm and positive bias of 4 volts, we have $v_0 = .12$. Further, for signal amplitude

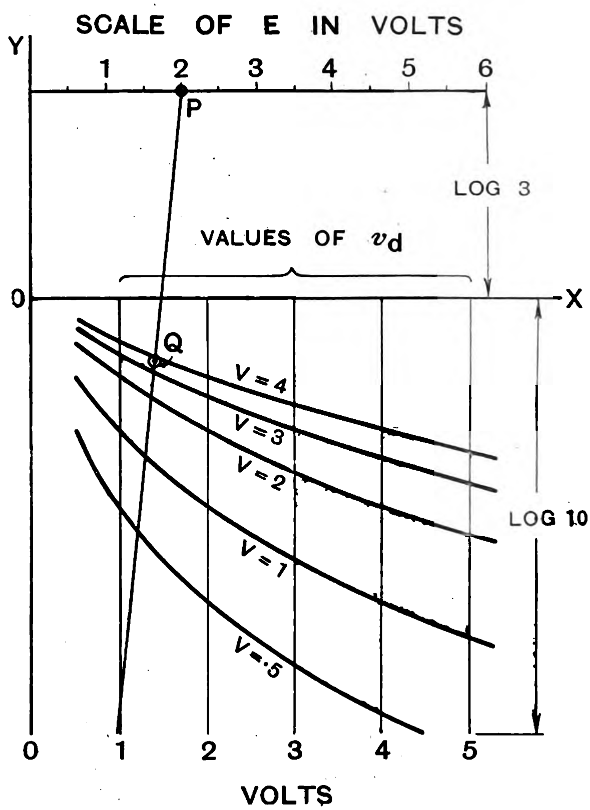


Fig. 12. *Chart relating the quantities* E, V *and* v_d *to* G, *the slope of the logarithmic characteristic. The point* P *corresponds to* E = 2 ; *the point* Q *corresponds to* V = 3.88, v_d = 1.34. *The gradient of* PQ *is that of the characteristic shown in Fig.* 9 : *the horizontal and vertical scales of Figs.* 9 *and* 12 *being in a fixed ratio.*

$E=2$, we obtain $v_s = -1.22$. Hence $V = 3.88$, while v_d, the required voltage shift, is 1.34. On Fig. 12 the slope line passes through a point Q satisfying these values.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 492 *of August issue.*)

PART III (CONTINUED).

7. Rules for Differentiating Combinations of Functions.

THIS section deals with technique rather than principles. As such it is likely to be dullish reading but will repay attention.

(A) *Differentiation of the Sum of a Number of Functions.*

Suppose it is required to differentiate

$$y = 4x^3 + 3x^2 + 2x + 10$$

The best method is essentially that indicated by Æsop in the fable about the bundle of sticks. The above function can be regarded as a sum of the simpler functions $4x^3$, $3x^2$, etc. Now it is fairly easy to show from the definition of a limit that the limit of the sum of a finite number of terms is equal to the sum of the limits of the separate terms. From this it follows at once that if u, v, w, etc., are functions of x, and

$$y = u + v + w + \text{etc.}$$

then

$$\frac{dy}{dx} = \frac{du}{dx} + \frac{dv}{dx} + \frac{dw}{dx} + \text{etc.}$$

Applying this to the example given,

$$dy/dx = 12x^2 + 6x + 2$$

Disappearance of the Constant Term.

Notice that in the above differentiation the 10 disappears. The disappearance of any constant term is inherent in the process of differentiation. This important fact must be borne in mind when the process is reversed. For example, if n is a positive integer, it has been shown that the d.c. of x^n is nx^{n-1}. But so also is the d.c. of x^n+C, where C is any constant number whatever. If, therefore, we are told that y is a function of x such that

$$dy/dx = nx^{n-1}$$

then we can only infer that

$$y = x^n + C$$

where C is some unknown "arbitrary" constant for the determination of which further information is required.

(B) *The Differentiation of a Product of Functions.*

If $f(x)$ and $g(x)$ are two functions of x, and

$$y = f(x)g(x)$$

then by definition,

$$\frac{dy}{dx} = \underset{h\to 0}{lt.}\ \frac{f(x+h)g(x+h) - f(x)g(x)}{h}$$

$$= \underset{h\to 0}{lt.}\ \frac{f(x+h)g(x+h) - f(x)g(x+h) + f(x)g(x+h) - f(x)g(x)}{h}$$

$$= \quad g(x)\,\frac{df(x)}{dx} + f(x)\,\frac{dg(x)}{dx}$$

or, putting this in a form which is rather easier to remember,

$$\frac{duv}{dx} = u\frac{dv}{dx} + v\frac{du}{dx}$$

Consider for example the two functions x^n and x^{-n}, n being a positive integer. The product of these functions is 1, and the d.c. of the product is therefore zero, *i.e.*,

$$\frac{dx^{-n}x^n}{dx} = x^{-n}\frac{dx^n}{dx} + x^n\frac{dx^{-n}}{ax} = 0$$

or

$$nx^{n-1}x^{-n} + x^n\,\frac{dx^{-n}}{dx} = 0$$

$$\frac{dx^{-n}}{dx} = -nx^{n-1}x^{-n}x^{-n}$$

$$= -nx^{-n-1}$$

which shows that the formula for the d.c. of x^n is true for negative indices.

It is easy to extend the above result to products of more than two terms. It will be found that

$$\frac{duvw}{dx} = uv\,\frac{dw}{dx} + uw\frac{dv}{dx} + vw\,\frac{du}{dx}$$

and so on.

(C) *The Differentiation of a Quotient.*

This can be derived from the preceding, just as the idea of a quotient is derived from that of a product.

If $y = u/v$ then $u = vy$.

The right-hand side can be differentiated by the rule for a product, and in this way it is easy to show that

$$\frac{dy}{dx} = \frac{1}{v^2}\left\{ v\frac{du}{dx} - u\frac{dv}{dx} \right\}$$

(D) *The Differentiation of a Function of a Function.*

This sounds tautological, for a function of a function of x is a function of x. However, in a case such as

$$y = 3(x^2 + 2x + 5)^2 + 7(x^2 + 2x + 5) + 8$$

it will generally be more convenient to treat y as a function of the variable (x^2+2x+5), which variable is itself a function of x. The function $y = log\ (sin\ x)$ is another instance. The general form is

$$u = f(x)$$

and

$$y = \phi(u) = \phi\{f(x)\}$$

Suppose x increases to $x+h$, in consequence of which u increases to $u+k$ and y to $y+m$. Then

$$\frac{du}{dx} = \underset{h\to 0}{lt.}\ \frac{k}{h}$$

and

$$\frac{dy}{du} = \underset{k\to 0}{lt.}\ \frac{m}{k}$$

Further, since the functions are assumed to be continuous, k will tend to zero as h tends to zero, so that

$$\frac{dy}{du} = \underset{h\to 0}{lt.}\ \frac{m}{k}$$

Therefore

$$\frac{dy}{du}\frac{du}{dx} = \underset{h\to 0}{lt.}\ \frac{m}{k}\ \underset{h\to 0}{lt.}\ \frac{k}{h}$$

It is easy to show from the definition of limit that the product of the limits of two terms is equal to the limit of the product of the terms so that

$$\frac{dy}{du}\frac{du}{dx} = \underset{h\to 0}{lt.}\left\{\frac{m}{k}\frac{k}{h}\right\}$$
$$= \underset{h\to 0}{lt.}\ \frac{m}{h}$$

since the quantities m, k, and h are not zero. But

$$\underset{h\to 0}{lt.}\ \frac{m}{h} = \frac{dy}{dx}$$

Therefore

$$\frac{dy}{dx} = \frac{dy}{du}\frac{du}{dx}$$

For instance, taking the first example quoted above

$$y = 3u^2 + 7u + 8$$

and

$$u = x^2 + 2x + 5$$
$$dy/du = 6u + 7$$
$$du/dx = 2x + 2$$

Therefore

$$dy/dx = \{6(x^2 + 2x + 5) + 7\}(2x + 2)$$
$$= 12x^3 + 36x^2 + 98x + 74$$

An important special case is that in which y is that function of x which makes

$$y^q = x^p,\ i.e.,\ y = x^{p/q}$$

The differentiation of y^q by the above rule gives

$$qy^{q-1}(dy/dx) = px^{p-1}$$

By substituting in this the value for y in terms of x and rearranging, it is easy to show that

$$dy/dx = (p/q)x^{(p/q)-1}$$

We can therefore say that

$$dx^n/dx = nx^{n-1}$$

for all real values of n, positive or negative, integral or fractional.

8. Standard Forms.

In order to acquire fluency in the applications of the calculus it is advisable to learn off by heart the differential coefficients of a number of the most common functions, just as one learns off by heart the multiplication tables at an earlier stage of one's mathematical education. With these standard forms and the above rules for dealing with simple combinations of functions the differentiation of any ordinary function is a comparatively simple matter. The more important of these standard forms will now be detailed.

(A) x^n.

It has already been shown that

$$dx^n/dx = nx^{n-1}$$

for all values of n.

(B) ϵ^x.

On account of its great importance, this case will be given in full. If $y=\epsilon^x$ then by definition,

$$\frac{dy}{dx} = \underset{h\to 0}{lt.} \frac{\epsilon^{x+h} - \epsilon^x}{h}$$
$$= \underset{h\to 0}{lt.} \epsilon^x \frac{\epsilon^h - 1}{h}$$
$$= \epsilon^x \underset{h\to 0}{lt.} \frac{\epsilon^h - 1}{h}$$

Now

$$\frac{\epsilon^h - 1}{h} = 1 + \frac{h}{2}\left\{1 + \frac{h}{3} + \frac{h^2}{3\cdot 4} + \frac{h^3}{3\cdot 4\cdot 5\cdot} + \text{etc. etc., } ad\ inf.\right\}$$

For values of h less than 1 the sum to infinity of the series in the brackets is less than

$1+h+h^2+h^3+h^4+$ etc., etc., *ad inf.* $=1/(1-h)$

(by Sect. 9 of Part I). Therefore the series in the brackets can be put equal to $K/(1-h)$, where K is less than 1 as long as h is less than 1. Therefore

$$\underset{h\to 0}{lt.} \frac{\epsilon^h - 1}{h} = \underset{h\to 0}{lt.}\ 1 + \frac{Kh}{2(1-h)}$$
$$= 1$$

so that $\quad dy/dx = d\epsilon^x/dx = \epsilon^x = y$

(It might appear that this could be proved more simply by differentiating term by term the series for ϵ^x. The series so obtained, however, is not necessarily equal to the differential coefficient of the sum of the original series, for the sum of the limits of an infinite number of terms is not necessarily equal to the limit of the sum. It generally is but it quite often isn't, and the assumption may never be made without question.)

Note that if

$$y=a\epsilon^{mx}=a(\epsilon^x)^m$$

then by the rule for the differentiation of a function of a function

$$dy/dx = am(\epsilon^x)^{m-1}\epsilon^x = am\epsilon^{mx} = my$$

Thus the function $a\epsilon^{mx}$ has the remarkable property that its rate of change is proportional to itself. Further, it is the only known function which has this property. In other words the most general solution of the differential equation

$$dy/dx = my$$

is

$$y=a\epsilon^{mx}$$

where a is an arbitrary constant number for the determination of which further information is required. This is the reason why the curious and rather awkward number $\epsilon=2.71828$ . . . is always turning up in applied mathematics and physics.

The rather more general case

$$y=a^x$$

can be derived at once by writing the constant a in the form ϵ^m, *i.e.*, m is $log_\epsilon a$ Then

$$y = a^x = (\epsilon^m)^x = \epsilon^{mx}$$

and

$$dy/dx = m\epsilon^{mx} = m(\epsilon^m)^x = a^x\ log_\epsilon a$$

(C) *Log* $_\epsilon x$.

This case can be derived from the preceding for if

$$y = log_\epsilon x$$
$$x = \epsilon^y$$

and the differentiation of both sides (the right-hand side being a function of a function of x) gives

$$1 = \epsilon^y\,(dy/dx)$$

so that

$$dy/dx = d\ log\ x/dx = 1/\epsilon^y = 1/x.$$

An obvious extension is

$$\frac{d\,log f(x)}{dx} = \frac{1}{f(x)}\ \frac{df(x)}{dx}$$

(D) *Sin x.*

The reader should have no difficulty in showing from the trigonometrical formulæ derived in Sect. 16, Part II, that

$$sin\ A - sin\ B = 2\ cos\ \frac{(A+B)}{2}\ sin\ \frac{(A-B)}{2}$$

so that

$$sin\ (x+h) - sin\ x = 2\ cos\left(x + \frac{h}{2}\right) sin\ h/2.$$

Therefore, if $y=sin\ x$

$$\frac{dy}{dx} = \underset{h\to 0}{lt.}\ cos\left(x + \frac{h}{2}\right)\frac{sin\ (h/2)}{h/2}$$
$$= cos\ x$$

for, as already shown in Part II, the limit of $(sin\ \theta)/\theta$ when θ tends to zero is 1.

In a precisely similar manner it can be shown that

$$d\,(cos\ x)/dx = -sin\ x$$

Notice that

$$d\,(sin\ mx)\,/\,dx = m\ cos\ mx,$$

by the rule for the differentiation of a function of a function.

The other trigonometrical functions are derived from these two, the sine and the cosine, as shown in Part II, and the d.c.s can therefore be calculated from the above rules relating to combinations of functions. Space will not permit of their being detailed individually but they are listed below for reference.

Function.	Differential Coefficient.
$tan\ x$	$sec^2\ x$
$cot\ x$	$-cosec^2\ x$
$sec\ x$	$sec\ x\ tan\ x$
$cosec\ x$	$-cosec\ x\ cot\ x$

So much for what may be called the ABC of the calculus. Not enough, perhaps, some may think. It certainly is rather concentrated, but the essence of the matter is there. Familiarity with the ideas involved can only be had by practice, and then more practice, and then some more. A few examples are given, but many more need to be worked by a beginner. A good plan is to express a function in two ways and differentiate each form. Work can be made more or less self checking in this way. (Examples: $(a+x)^3$ and $a^3+3a^2x+3ax^2+x^3$; $tan\ 2x$ and $(2\ sin\ x\ cos\ x)/(cos^2x-sin^2x)$; and so on.)

9. Successive Differentiation.

This does not introduce any new ideas, but only some more "shorthand." If y is a function of x, then in general dy/dx will also be a function of x and as such can be differentiated with respect to x, giving

$$\frac{d}{dx}\left(\frac{d}{dx}y\right)$$

Since this is rather cumbersome to write, it is abbreviated to

$$d^2y/dx^2$$

the d's and dx's being, so to speak, multiplied together as if they were numbers (which of course they aren't). It is merely a convenience of notation. The process can obviously be extended, giving d^3y/dx^3, d^4y/dx^4, etc., d^ny/dx^n being referred to as the nth differential coefficient of y with respect to x, or sometimes as the nth derivative. As an example, if

$$\begin{aligned} y &= ax^3 \\ dy/dx &= 3ax^2 \\ d^2y/dx^2 &= 2.3ax \\ d^3y/dx^3 &= 2.3a \\ \text{and}\quad d^4y/dx^4 &= 0 \end{aligned}$$

so that the process terminates. On the other hand a function such as $sin\ x$ can be differentiated for ever. In this matter the trigonometric functions have a peculiar property which can be illustrated by

$$\begin{aligned} y &= a\ sin\ mx + b\ cos\ mx \\ dy/dx &= am\ cos\ mx - bm\ sin\ mx \\ d^2y/dx^2 &= -am^2\ sin\ mx - bm^2\ cos\ mx \\ &= -m^2\ y \end{aligned}$$

No other function can be found which has this property that the second differential coefficient is equal to the function multiplied by a negative number. In other words the most general solution of the differential equation

$$d^2y/dx^2 = -m^2y$$

is $$y = a\ sin\ mx + b\ cos\ mx$$

where a and b are constant numbers which can only be determined by additional information. Suppose, for instance, we are given that

$$\begin{aligned} d^2y/dx^2 &= -169\ y\ (i.e.,\ -13^2\ y) \\ y &= 10 \text{ when } x=0 \\ dy/dx &= 26 \text{ when } x=0 \end{aligned}$$

Then the general solution is

$$y = a\ sin\ 13x + b\ cos\ 13x$$

so that

$$dy/dx = 13a\ cos\ 13x - 13b\ sin\ 13x$$

Therefore when x is 0 we have

$$(y)_0 = 10 = b$$

$$(dy/dx)_0 = 26 = 13a,\ i.e.,\ a=2$$

giving as the complete particular solution

$$y = 2\ sin\ 13x + 10\ cos\ 13x.$$

10. Partial Differentiation

Here again there is no new idea but only additional notation. As already pointed out in Part I, two or more independently variable numbers can be combined in a variety of ways to give another number. For instance if x and y are independent variables,

$$z = ax^2 + bxy + cx^2$$

is a function of the two variables x and y. Such a function could be represented geometrically by taking x and y as rectangular co-ordinates and z as the vertical height above the x, y plane at the point x, y. The equation would then define a surface. Now in general the rate of change of z, $i.e.$, the slope of the surface, will depend on the

direction in which it is measured, a fact which is demonstrated afresh every time the driver of a wagon zig-zags up a hill which is too steep for his horses. The term "differential coefficient" is therefore indefinite unless the direction is specified in some way. There are two directions which naturally suggest themselves and which are generally of more interest than any others —the directions of the x and y axes. Moving in the direction of the x axis means that y is kept constant. (If this is not immediately obvious, the reader should draw the axes. Then it will be.) As long as y is kept constant z is in effect a function of the single variable x and has a differential coefficient with respect to x, *i.e.*, a slope in the direction of the x axis. That is what is meant by dz/dx in such a case, only it is written $\partial z/\partial x$ in order to distinguish it from the case in which z is a function of x only, in the full ordinary sense of that phrase. It is called the partial differential coefficient of z with respect to x. Similarly for $\partial z/\partial y$. For instance, in the above case, *i.e.*,

$$z = ax^2 + bxy + cy^2$$
$$\partial z/\partial x = 2ax + by$$

since cy^2 is by definition a constant as far as this rate of change is concerned. Similarly

$$\partial z/\partial y = bx + 2cy.$$

Both these partial differential coefficients will in general be functions of x and of y, as they are in the above case, and will therefore themselves have further partial differential coefficients, defined in the same way. Thus

$$\frac{\partial}{\partial x}\left(\frac{\partial z}{\partial x}\right)$$

which is written for shortness $\partial^2 z/\partial x^2$ is $2a$, and

$$\frac{\partial}{\partial y}\left(\frac{\partial z}{\partial x}\right)$$

which is abbreviated to $\partial^2 z/\partial y\partial x$ is b. Notice that $\partial^2 z/\partial x\partial y$ and $\partial^2 z/\partial y\partial x$ have different meanings as defined above. It can be shown, however, that if they both exist they will be equal, as they are in the present instance. The proof is rather beyond the scope of this work.

The reader should have no difficulty in showing that if z is a function of a function of x and y, *i.e.*,

$$z = f(u)$$

where

$$u = \phi(x, y)$$

then

$$\frac{\partial z}{\partial x} = \frac{df(u)}{du}\frac{\partial u}{\partial x}$$

and

$$\frac{\partial z}{\partial y} = \frac{df(u)}{du}\frac{\partial u}{\partial y}$$

The proof follows exactly the same lines as for the rule for the differentiation of a function of a function and is omitted to save space. Consider, for instance, the anode current of a triode valve, which, using the usual symbols, can be expressed in the form

$$i_a = f(v_a + \mu v_g + \alpha)$$

where α is a constant. The quantities v_a and v_g are independent variables and have probably been varied independently by readers of this paper on many occasions. The relation can be put in the form

$$i_a = f(V) \text{ where } V = v_a + \mu v_g + \alpha$$

which gives i_a as a function of a function of the two variables. The slope of the anode current—grid voltage characteristic is

$$\frac{\partial i_a}{\partial v_g} = \frac{df(V)}{dV}\frac{\partial V}{\partial v_g} = \mu\frac{df(V)}{dV}$$

and of the anode current—anode voltage characteristic

$$\frac{\partial i_a}{\partial v_a} = \frac{df(V)}{dV}\frac{\partial V}{\partial v_a} = \frac{df(V)}{dV}$$

so that

$$\frac{\partial i_a}{\partial v_g} = \mu\frac{\partial i_a}{\partial v_a}$$

Notice that $df(V)/dV$ is the slope of what is sometimes called the "lumped volts" characteristic.

11. Critical Values.

Given a circuit or some other combination of apparatus the performance of which depends on, or, in other words, is a function of, some variable condition of operation, it is generally desirable and sometimes very important to know what condition of operation will give the best performance. Suppose, for instance, that a battery is to supply electrical power to some variable load resistance. What will be the magnitude of the resistance which will absorb the maximum power from a battery of given characteristics? Such problems are of frequent occurrence in applied electricity, and the technique of the

differential calculus finds one of its most valuable applications in the solution of such problems.

First, let us examine a little more closely the example quoted above in order to get a

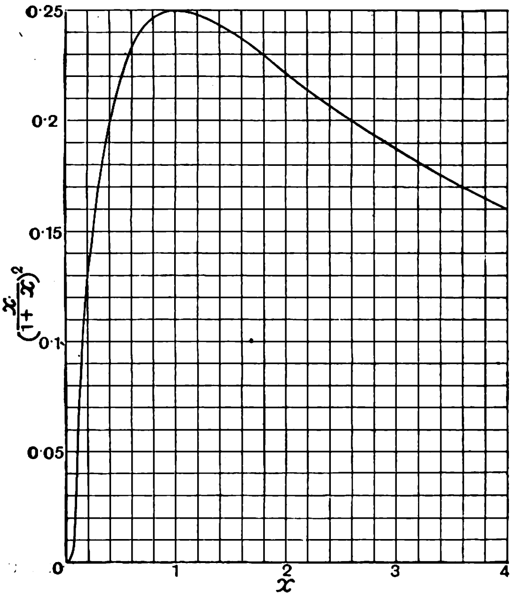


Fig. 30.

clearer idea of the nature of the problem. If the "open circuit" E.M.F. of the battery is e volts, its internal resistance R_0 ohms, and the resistance of the load R ohms, then the current will be

$$i = e/(R_0 + R)$$

amperes, by Ohm's Law. The power absorbed by the load will be

$$p = i^2R = \frac{R}{(R+R_0)^2}e^2.$$

and is thus a function of R for given constant values of e and R_0. It is therefore also a function of the ratio R/R_0, and for the present purpose is more conveniently expressed in terms of this ratio. Putting x for R/R_0,

$$p = \frac{x}{(1+x)^2}\,\frac{e^2}{R_0}$$

and the variation of the power p with R is seen to be essentially the variation with x of the function $x/(1+x)^2$. Calling this function y, the variation of y with x is shown in Fig. 30. This is the simplest form of "efficiency curve" and in most practical cases the variation of electrical efficiency will be of this character. It appears from the diagram that y reaches a pronounced maximum value of $\frac{1}{4}$ when x is 1, *i.e.*, when $R = R_0$. Therefore in this particular case the maximum power obtainable from the battery is $e^2/4R_0$, and the "optimum" load corresponding to this output is a load equal to the internal resistance of the battery.

Now let us see how this same conclusion could be reached without the trouble of drawing the curve of the function, by applying the technique of the differential calculus.

In Fig. 31 the point P_1 is assumed to correspond to the maximum value reached by y in the range 0 to x_1 of x, y being a continuous function of x in the range illustrated in the diagram. Up to P_1, y increases with x so that dy/dx is positive. From P_1 to P_2 y decreases with x so that dy/dx is negative. The point P_1 therefore separates positive and negative values of dy/dx. It will be assumed that the variation of dy/dx is continuous. Then the point of separation of positive and negative values is the value

$$dy/dx = 0$$

(*i.e.*, the tangent at P_1 is parallel to the x axis). Notice that from 0 to x_2, dy/dx

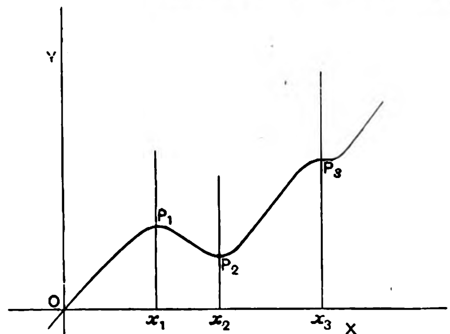


Fig. 31.

decreases continuously. This means that $d(dy/dx)/dx$, or d^2y/dx^2 is negative throughout this range and therefore negative at P_1. Thus for the maximum value at P_1 (corresponding to the value x_1 of x)

$$dy/dx = 0$$
$$d^2y/dx^2 < 0 \quad (\textit{i.e.}, \text{ is negative})$$

or, another way of writing it,

$$dy/dx_1 = 0$$
$$d^2y/dx_1^2 < 0$$

In a precisely similar manner, the point P_2 will be a minimum if

$$dy/dx_2 = 0$$
$$d^2y/dx_2^2 > 0 \quad (i.e., \text{ is positive}).$$

It is important to notice that the condition $dy/dx=0$ alone will not necessarily determine a maximum or minimum value of y. At P_3, for instance, the tangent is parallel to the axis of x, so that $dy/dx=0$. However, dy/dx is positive on both sides of P_3. Therefore zero is a minimum value of dy/dx, and d^2y/dx^2 passes through zero at P_3. This is known as a point of inflection.

The example already considered will serve as an illustration of a maximum value.

If $$y = x/(1+x)^2$$

$$dy/dx = \{(1+x)^2 - 2x(1+x)\}/(1+x)^4$$

which reduces to

$$dy/dx = (1-x)/(1+x)^3$$

so that

$$dy/dx = 0 \text{ when } x = 1$$

Also it is easy to show that

$$d^2y/dx^2 = -2(2-x)/(1+x)^4$$

which is negative when $x=1$. Therefore y passes through a *maximum* value ($\frac{1}{4}$) when $x=1$.

The following is a very useful practical point in connection with maximum and minimum values. It frequently happens that the quantity to be investigated can be regarded as a function of a function, *e.g.*,

$$y = \phi(u)$$

where

$$u = f(x)$$

The critical condition is then

$$\frac{dy}{dx} = \frac{d\phi(u)}{du} \cdot \frac{du}{dx} = 0$$

so that either

$$\frac{d\phi(u)}{du} = 0$$

or

$$\frac{du}{dx} = 0$$

and in the majority of cases it will be the second condition that counts. Take, for instance, the case

$$y = 1/\sqrt{R^2 + (\omega L - 1/\omega C)^2}$$

where R, L, and ω are constant numbers and C is variable. This is in effect

$$y = 1/\sqrt{u}$$

where

$$u = R^2 + (\omega L - 1/\omega C)^2$$

There is no critical condition for dy/du, but

$$du/dC = 2(\omega L - 1/\omega C)/\omega C^2$$

which will be zero when $\omega L = 1/\omega C$. There is no need to write out the whole differentiation in full in this or similar cases.

Examples.

1. Find the first, second and third derivatives of
   i. $ax^2 + bx + c$.
   ii. $a + b/x + c/x^2$.
   iii. $30 \sin x + 15 \sin 2x + 10 \sin 3x$.
   iv. $\varepsilon^{ax} \sin bx$.
   v. a^x.
   vi. $a^x \log(\sin x)$.

2. Solve the equation

$$dQ/dt = -Q/CR$$

where C and R are numbers, given that Q is 10 when t is 0.

3. Solve the equation

$$d^2i/dt^2 = -25m^2t$$

where m is a number, given that i is 0 when t is 0 and that i is 10 when t is $\pi/2m$.

4. Find

$\partial z/\partial x$, $\partial z/\partial y$, $\partial^2 z/\partial x^2$, $\partial^2 z/\partial y^2$, $\partial^2 z/\partial x\partial y$, $\partial^2 z/\partial y\partial x$

for

$$z = ax^2 + bxy + cy^2$$

and

$$z = \varepsilon^{ax+by} \sin xy.$$

5. Discuss the critical values of
   i. $x/(1 + 2ax + x^2)$.
   ii. $x/(1 + x^2)$.

Answers to Examples in August Issue.

1. If θ is the angle between the two vectors the area of the parallelogram is

$$ab \sin\theta = ab\sqrt{1 - \cos^2\theta}$$
$$= \sqrt{(ab)^2 - (\mathbf{a}.\mathbf{b})^2}$$

2. Use formula

$$c^2 = a^2 + b^2 - 2ab \cos\gamma \;.\; c = 20.09 \text{ cms.}$$

3. $Tan\ 60° = sin\ 60°/\sqrt{1 - sin^2 60°} = 1.732.$

$Sec\ 60° = 1/\sqrt{1 - sin^2 60°} = 2.0.$

4. i. Express $tan\ (A+B)$ as $sin\ (A+B)/cos\ (A+B)$ and divide top and bottom by $cos\ A\ cos\ B$.

ii. Put $A = B = \theta$ in the preceding result.

iii. and iv. Expand $(cos\ \theta + j\ sin\ \theta)^3$ and equate to $(cos\ 3\theta + j\ sin\ 3\theta)$.

. i. 5; 6.403; 7.81.

ii. $r = 19.21 \quad \theta = 51°21'$

iii. $r = 3.606 \quad \theta = 56°18'$

iv. $r = 1.46 \quad \theta = 1°56'$

v. $r = 0.484 \quad \theta = -50°36'$

6. These vectors are not parallel and their sum is zero.

7. $1.59 + .626j$; $-1.339 + 1.065j$; $-.541 - 1.621j$.

8. Since $ds/dt = 50 + 100t$, $s = 50t + 50t^2 + C$, where C is an unknown constant. Therefore time travelled in an hour from instant $t = 0$ is

$50 \times 3{,}600 + 50 \times 3{,}600^2$ cms. $= 6{,}482$ kilometres.

9. $ds/dt = 500 - 10t$. This is 0 when $t = 50$ seconds. Putting $t = 50$ in the original equation gives a distance of .125 kilometre. It will return to starting point in 100 seconds.

Book Reviews.

NAVIGATIONAL WIRELESS. By S. H. Long, D.Sc., M.I.E.E. 164 pp.+xi. with 156 Figs. Chapman & Hall. Price 12s. 6d. net.

This book is written with a double object, viz., to enlighten the radio operator on the subject of navigation and to enlighten the navigating officer on the subject of radio direction-finding and thus to develop a much-to-be-desired close co-operation between them. We can say at once that the book is well written and well illustrated and admirably adapted to fulfil its object. It devotes the first two chapters to elementary electrical theory and the principles and application of the 3-electrode valve, then follow two chapters on the principles of direction-finding by the various methods which have been devised. A chapter is devoted to the practical installation of a single-frame aerial on a ship, with special reference to the apparatus made by Siemens Bros., the author being connected with this firm. The sixth chapter deals in a very thorough and practical manner with the errors due to the metal mass of the ship, other errors such as those due to night effect and coastal refraction being dealt with in a later chapter. Three chapters are devoted to maps and the navigational side of direction-finding and a concluding chapter to beacon stations and under-water acoustic methods of signalling and sounding. There are five appendices of assorted information. In looking through the book we noted a few points which might have been put more clearly. For instance, on page 2, where it is stated that a drift of $10^{19}/1.57$ electrons per second would produce a charge of 1 coulomb, and on page 5 where we read that "the number of changes of direction per second is termed the *half frequency*. Frequencies up to 1,000 reversals per second are usually considered as low frequencies." The italics are in the original and they emphasise the confusion. If one is ever unwise enough to call the number of changes of direction per second anything at all, we trust that it will be something less misleading than the half frequency, seeing that it is twice the frequency. On page 14 the author seems to have a confused idea as to what constitutes the primary and secondary of a transformer when he says that "the transformer should be of the step-down type, *i.e.*, one in which the large voltage and small current in the *secondary* is transformed into a small voltage and comparatively large current in the *primary*"; this is not a misprint as the same mistake occurs elsewhere on the same page.

The treatment of the E.M.F. induced in an oscillatory circuit on page 33 is far from clear, the idea being apparently that the E.M.F. induced in the aerial increases as the aerial is tuned. We doubt whether it is quite correct to say on page 55 that the Robinson or Cranwell system of direction-finding works on positions of maximum signals; the reversal of the auxiliary coil is equivalent to swinging a single coil over a large angle and thus balancing the signals on either side of the maximum but considerably removed from it. These are minor criticisms and the book is one which can be recommended to those interested in the subject.

G.W.O.H.

EXPERIMENTAL RADIO. By R. R. Ramsey. Second Edition, 109 pp. Published by the author at the University Book Store, Bloomington, Indiana, U.S.A. Price 2 dollars.

The author is Professor of Physics at the University and the book is a mimeographed collection of laboratory instructions for carrying out 85 experiments dealing with radio work. Very complete instructions are given together with the underlying theory where necessary, and references given with each experiment to the relevant pages of several of the best known text books. The experiments cover all the practical work which a student would normally do in any course in radio-telegraphy. We have one adverse criticism to make and that is that the diagrams are in many cases very badly drawn; if the author replied that they were good enough for their purpose we should retort that they were calculated to cultivate an untidy habit in the writing up of experimental results, and in the setting up of apparatus. Apart from this we have nothing but praise for the book which should prove invaluable to those who have to plan and conduct a laboratory for radio instruction.

G.W.O.H.

A Reed Rectifier for Battery Charging.

The Construction of a Simple, Silent and Non-sparking Instrument.

By C. O. Browne, B.Sc.

A GREAT many amateurs are desirous of doing their own accumulator charging from the public lighting mains, but are confronted with the difficulty that their supply is alternating. Many resort to the Nodon cell or some other form of chemical rectifier, and others have arranged systems of mechanical rectifiers, but unfortunately very often have given them up in disgust. It is hoped, therefore, that the following somewhat detailed description of a vibrating reed rectifier and charging board built by the author will provide fresh stimulus to those who are anxious to have some economical means of charging accumulators from A.C. mains.

Details of the action of reed rectifiers have been published previously in *E.W. & W.E.* and the apparatus to be described is one of the simpler types employing only half-wave rectification. A modification is suggested, however, whereby both halves of the wave are rectified. Unlike the usual run of reed rectifiers, that possessed by the author has a mercury break and has the advantage that when properly adjusted it is absolutely silent in operation. Again, the apparatus is far more economical than the Nodon or Tantalum rectifier, as the transformer supplying the current steps down to ten volts only, there being practically no loss due to the internal resistance of the rectifier.

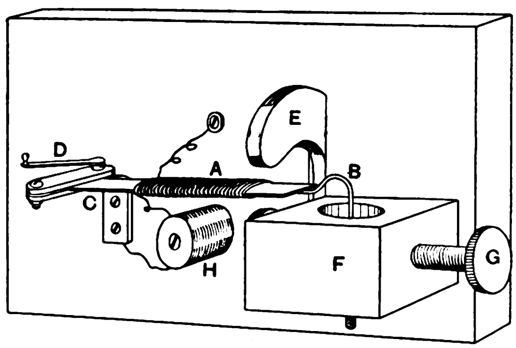


Fig. 1.

Details of the reed system may be gathered largely from the perspective diagram Fig. 1. The reed *A* consists of a piece of stalloy iron wound with 200 turns of 42 D.S.C. wire, to which is soldered the dipper *B* consisting of a short length of iron or platinum wire.

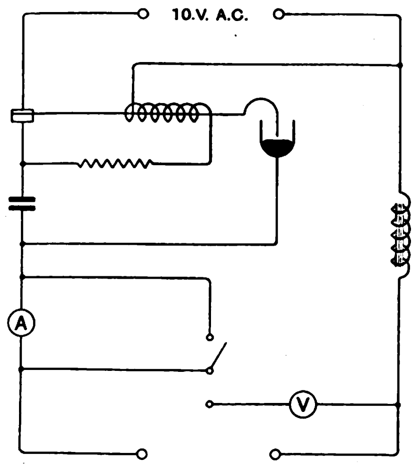


Fig. 2.

The other contact is a mercury cup *F* cut in a block of ebonite; provision being made to adjust the level of the mercury by the screw *G*. A clamp *C* made from a few pieces of odd brass and two screws serves to hold the end of the reed. The rough adjustment of the period of vibration of the reed to that of the mains is provided by slipping the reed in the clamp, and the fine tuning obtained by loosening or tightening one of the clamp screws mentioned by means of the lever *D*. A permanent magnetic field is maintained across the end of the reed by the telephone magnet *E*. Connections are made as in Fig. 2, the winding on the reed being in series with a resistance (*H*, Fig. 1) to limit the amplitude of vibration to 3 or 4 mm. and the whole shunted across the input.

Other necessaries to complete the equipment are a $2\mu F$ condenser bridged across the mercury break to prevent sparking, and

a small choke consisting of about 40 turns of thick wire wound on an iron core in series with the output. The ammeter and voltmeter do not call for any particular attention, but it should be noted that since only half-way rectification is employed, if the ammeter is of the moving iron variety it will not indicate the mean value of the charging current. To obtain the mean value the current indicated must be multiplied by the factor $2/\pi$ or .64 approximately. The same factor applies to the readings of a moving iron voltmeter when there is not an accumulator connected to the output. Moving coil instruments will indicate the mean values. Although a rheostat has not been included in Figs. 2 and 3, this accessory may be inserted in the lead from the reed to the ammeter. The single pole double-throw switch cuts out the meters when they are not required.

Fig. 3 suggests an arrangement for a rectifier for full-wave rectification, the two reeds being held under one clamp situated in the same magnetic field and provided with independent mercury cups. The windings on the reeds should be so arranged that there is a phase difference of 180 degrees between their movements. Thus, by adjusting the levels of the mercury in the cups, the two reeds could be prevented from making contact at the same time. A certain amount of latitude might be expected in this adjustment since the contacts are made and broken when the current from the secondary of the transformer is zero.

For a trial the half-wave rectifier was left running continuously day and night without attention for a week at 6 volts and 1.5 amps,

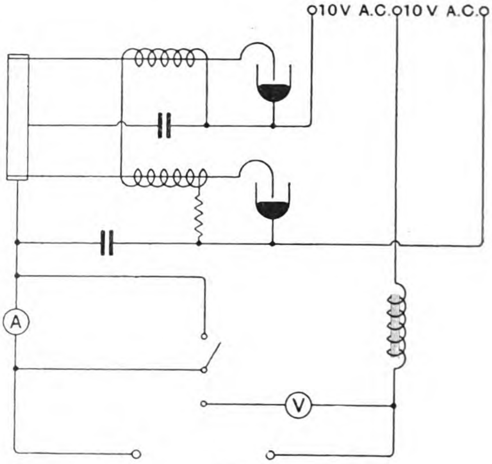


Fig. 3.

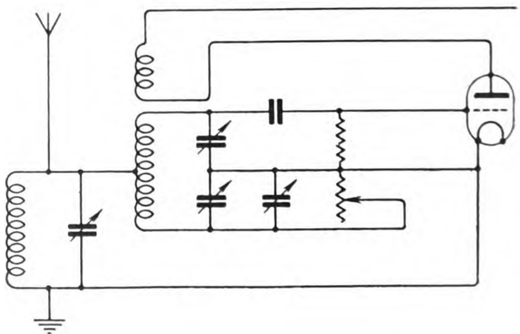
as read on moving iron instruments, and has now been in use for two years charging for 24 hours each week. The only renewal necessary has been that of the mercury every three or four months, and the initial cost apart from that of the condenser and meters was nothing.

Design and Construction of a Superheterodyne Receiver.

CORRECTION NOTE.

Our attention has been drawn to an error which appeared in Fig. 13 illustrating the article on "Design and Construction of a Superheterodyne Receiver," by P. K. Turner, A.M.I E.E.

The corrected figure is here reproduced and should replace that on page 339 of the June, 1927, issue.



Note on the Measurement of Dielectric Losses and Permittivity at Radio Frequencies.

By Raymond M. Wilmotte, B.A.

IN measuring the loss and permittivity ot a solid dielectric, it is usual to place the sample between two electrodes (which may be of mercury), thus forming a condenser, which is measured by any of the usual methods. The permittivity is then calculated from the size of the electrodes and their distance apart.

This calculation, however, is liable to error due to the edge effects, which are not wholly accounted for in the formulæ. Thus, suppose the two electrodes are made of equal circular plates of radius r and kept at an average distance b apart, if we neglect the edge effects, the capacity will be given by

$$c=\frac{Kr^2}{3.6b}\mu\mu\mathrm{F} \quad \ldots \quad (1)$$

where K is the permittivity of the dielectric.

Kirchhoff has calculated the case to allow for the edge effect, when the thickness and the distance apart of the electrodes is small compared with their radius. The capacity that has to be added to formula (1) to give the true geometric capacity between the electrodes is

$$\delta c=\frac{Kr}{3.6\pi}\left[\log_\epsilon\frac{16\pi(b+t)r}{b^2}+\frac{t}{b}\log_\epsilon\frac{b+t}{t}-3\right] \quad (2)$$

where t is the thickness of the electrodes (of equal radius r).

When the capacity to be measured is of the order of 100 or 200$\mu\mu$F, as often occurs, and mercury is used, it will often be found that this correction on formula (1) represents 5 per cent. or even more of the total. Even this correction, however, is only a rough approximation, for the thickness of the mercury electrodes can hardly be less than 2 mm., which will be comparable with the thickness of the dielectric, so that the stray field will pass partly through the dielectric and partly through air. There will also be a direct capacity of the insulated electrode to earth, which cannot be calculated in practical cases. Tinfoil may be used instead of mercury to make the electrodes thin and the correction given by equation (2) apply more exactly; but the contact between the electrodes and the dielectric will not be so good, unless a conducting liquid be inserted between the two. This will generally take the form of an electrolyte, but the water may be absorbed by the dielectric and thus alter its properties. All these errors will gain in importance, if the sample under test is thick.

To obtain true results, the use of a guard ring and a screen appear desirable, when equation (1) will hold together with a small correction given by Maxwell to allow for the small distance between the guard ring and the electrode. This correction is given by

$$\delta c=\frac{r\omega}{3.6\,(b+0.22\omega)}\left(1+\frac{\omega}{2r}\right)\mu\mu\mathrm{F} \quad \ldots \quad (3)$$

where ω is the width of the channel between the guard ring and the electrode. The ratio of r to b can have any value so long as this is large compared to ω and the width of the guard ring is at least 4 or 5 times b.

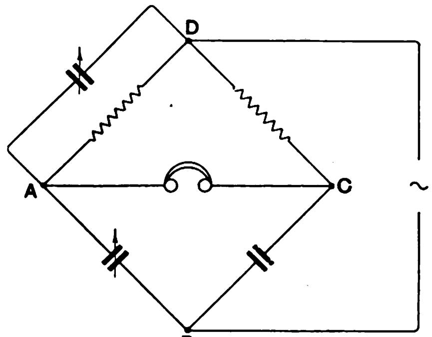


Fig. 1.

At low frequencies, where bridge methods of measurement can be used, there should be no difficulty in using a guard ring and keeping it at the potential of the insulated electrode. Thus in the equal armed bridge, Fig. 1, the guard ring can first be connected to A and then to C. Let C_1, C_1' be the readings of the condenser in the arm AB, and C_0, C_2 be the capacities of the guard ring

and plate respectively to the other electrodes.

Hence $C_1 + C_0 = C_2$

and $C_1' = C_0 + C_2$.

Therefore $C_2 = \frac{1}{2}(C_1 + C_1')$.

The condenser in the arm AD is to balance the resistance component of the condenser undeı test.

Otherwise a system can be adopted similar to a Wagner earth having the neutral point connected to the guard ring as shown in Fig. 2.

At high radio frequencies bridge methods have not yet been found satisfactory, so that the methods suitable for low frequencies will not apply. The following method should, however, prove satisfactory. The E.M.F. is induced in a stranded coil B (Fig. 3). One of the strands is connected to the guard ring and to the earthed electrode of C. The

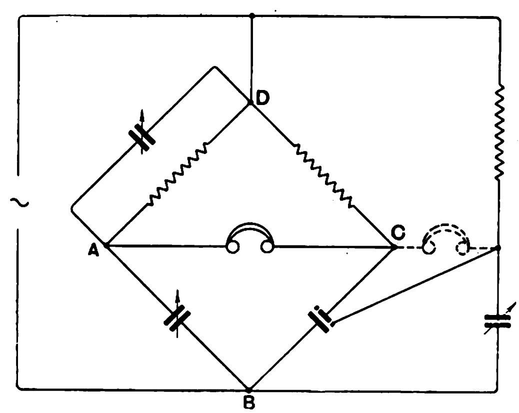


Fig. 2.

other strands are connected as usual to the condenser C and the condenser to be measured. In this way the guard ring is always at the same potential (except for the small ohmic drop) as that of the insulated plates of condenser C. The circuit is tuned with the plate D in and then out of the circuit. If K_1 is the difference in the two readings of the condenser C, and C_0 is the capacity representing the tubes of force from the shield to the upper side of plate D, then the capacity required is $(K_1—C_0)$. Let this be C_1.

It will be seen that the ammeter A in Fig. 3 does not measure the current through the guard ring, so that measurements of the effective resistance of the condenser can be made in the usual way by the resistance variation or other method.

The value of C_0 can be found in the following way. Once found, it can be used for all cases, for it will not vary appreciably with the thickness of the electrode or of the dielectric.

Let C_2 be the geometric capacity between the shield and the lower electrode including the earth capacities.

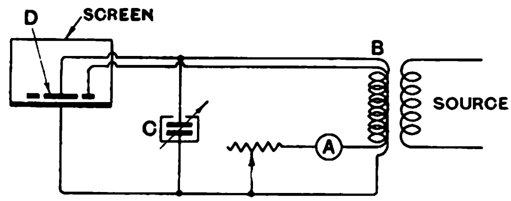


Fig. 3.

The capacity between the electrode D and the lower electrode with the screen disconnected from the lower electrode is measured as before, keeping the guard ring at the same potential as D. Let K_2 be the capacity measured. The screen is then connected to the electrode D and the capacity again measured. Let this be K_3.

Hence $K_1 = C_1 + C_0$

$$K_2 = C_1 + \frac{C_0\ C_2}{C_2 + C_0}$$

$$K_3 = C_1 + C_2.$$

From these three equations we find—

$$C_0 = K_1 - K_2 + \sqrt{K_2^2 + K_3K_1 - K_1K_2 - K_2K_3}$$

The guard ring could be cut out of a brass sheet with a metal ring about 0.5 cm. in height along the inner circumference. A thin rubber band just overlapping the lower edge of the ring could be stuck on to it. (A section is shown in Fig. 4.) The sample

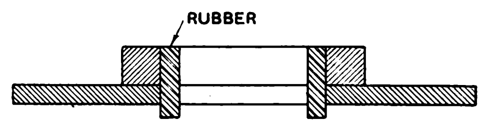


Fig. 4.

would be floated on mercury, the guard ring put on and the mercury poured within the ring, thus forming the insulated electrode. The whole would then be covered by the metal screen.

It is necessary to allow the rubber to overlap the guard ring slightly in order to allow for any irregularities in the surface of the sample.

Abstracts and References.

Compiled by the Radio Research Board and reproduced by arrangement with the Department of Scientific and Industrial Research.

PROPAGATION OF WAVES.

ON THE NATURE OF WIRELESS SIGNAL VARIATIONS —I.—E. V. Appleton and J. A. Ratcliffe. (*Proc. Roy. Soc., A*, 115, pp. 291-305, July, 1927.)

The paper is summarised as follows :—

1. Two methods of measuring the angle of incidence of downcoming wireless waves are described. The two methods have different ranges of applicability. Both involve photographic registration. The first method utilises the ordinary night-time signal variations and can be employed in connection with any steady transmitting station. It only yields useful results if the natural signal variations are small. The second method requires a controlled wavelength change at the transmitter, but may be used even when the natural signal variations are large.

2. The mean values of the angle of incidence, as measured by these two methods, for the periods immediately following sunset and preceding sunrise, show a close agreement, and lead to an effective height of 90-100 kilometres for the atmospheric deflecting layer.

3. Observations of the angle of incidence, made by these methods, indicate a diurnal variation in the height of the ionised layer, which is found to be higher in the middle of the night than during the sunset and sunrise periods.

4. Comparatively rapid fluctuations have been observed in the angle of incidence of downcoming waves. Such fluctuations are not considered as being due to variations in the height of the ionised layer, but are explained by supposing that "reflection" takes place at different points on a layer the mean height of which is sensibly constant. Such variations might be expected if the layer were not of sensibly uniform horizontal stratification.

ON THE NATURE OF WIRELESS SIGNAL VARIATIONS —II.—E. V. Appleton and J. A. Ratcliffe. (*Proc. Roy. Soc., A.*, 115, pp. 305-317, July, 1927.)

The paper is summarised as follows :—

1. An account is given of experiments designed to yield information on the nature of the variations of downcoming wireless waves, which are responsible for nocturnal signal variations. By employing a receiving assembly which is a combination of a loop and vertical aerial, it has been possible to eliminate the effects of the ground waves at the receiving station and to study the characteristics of the downcoming wave directly. Large variations in the intensity of the downcoming waves are found.

2. It is pointed out that fading may be due to changes in any of the following variables which determine the nature of the downcoming waves :—

(*a*) Angle of incidence ;
(*b*) Intensity ;
(*c*) Phase ;
(*d*) Polarisation.

It is shown that for wavelengths of about 400 metres and distances of about 80 miles, fading is chiefly due to changes in the intensity of the downcoming waves. Variations in the phase relation between ground and sky waves are a secondary cause of fading. Changes in the angle of incidence or polarisation of the downcoming wave are not responsible in any very marked degree for signal variations.

3. The downcoming ray has been shown to be of complex polarisation, having electric vectors both in, and at right angles to, the plane of propagation. Similar intensity variations are found in both these vectors.

4. The use of a suppressed atmospheric ray system in reception for the minimisation of fading, and in transmission, for preventing the emission of upward rays, is discussed. Such a system may be used to find the angle of incidence of downcoming rays in the absence of direct rays.

SHORT-WAVE WIRELESS TELEGRAPHY.—T. L. Eckersley. (*Journ. Inst. Elect. Engineers*, 65, pp. 600-644, June, 1927.)

A paper read before the Wireless Section, 2nd March, 1927.

Abstracts of the paper were published in *E.W. & W.E.*, of April, pp. 213-222, and in the *Electrical Review*, of 17th June, pp. 996-997.

TRANSMISSION OF ELECTRIC WAVES THROUGH THE IONISED MEDIUM.—T. L. Eckersley. (*Philosophical Magazine*, 4, 20, pp. 147-165, July, 1927.)

A mathematical investigation showing that in a medium containing free electrons there is a certain critical frequency characterised by the fact that waves of lower frequency than this cannot travel through the medium.

The physical reason for the existence of such a critical frequency is shown to be connected with the fact that the electrons in the medium rob the wave of its momentum, and at the critical frequency also rob this momentum completely so that the wave can travel no farther.

This fact is shown to be connected with the theory of Compton scattering, in which an individual quantum gives up its momentum in collision with an electron. The wave is brought to a standstill when all the quanta (per unit volume) are brought into collision with the electrons, which event occurs when the critical frequency is approached.

SUR LES PROPRIÉTÉS DIÉLECTRIQUES DES GAZ IONISÉS ET LA PROPAGATION DES ONDES ELECTROMAGNÉTIQUES DANS LA HAUTE ATMOSPHÈRE (On the dielectric properties of ionised gases and the propagation of electro-magnetic waves in the upper atmosphere).—H. Gutton and J. Clément. (*L'Onde Electrique*, 6, 64, pp. 137-151.)

Description of experiments undertaken with a view to observing the apparent diminution of the dielectric constant of an ionised gas predicted by Eccles' theory. This diminution was verified by the authors with the gas at low pressure, but was found to cease as the ionisation becomes greater, a sudden increase occurring when the ionisation reaches a certain value, which is the lower the longer the wavelength. Eccles' theory does not predict this increase, but the theory does not take into consideration the mutual action between the ions. The experimental results are completely explained if this mutual action introduces quasi-electric forces which determine the existence of a period of resonance. It is shown how this resonance can account for the reduced range and irregularity of signals transmitted on wavelengths in the neighbourhood of 200 metres (*cf. Comptes Rendus*, 184, pp. 441 and 676; these abstracts *E.W. & W.E.*, May and June, 1927, pp. 312 and 368 respectively).

PENETRATION OF RADIO WAVES.—A. Eve and D. Keys. (*Nature*, 2nd July, 1927, p. 13.)

Information as to the extent to which wireless waves penetrate into the ground has become of special interest owing to there now existing two or three geophysical methods of ore prospecting which definitely attempt to use wireless waves for the detection of ore beneath the earth.

While experiments with submerged submarines prove that radio waves will not pass more than about 50 or 60 feet into seawater, no matter what the wave-length, the question of penetration into fresh water, damp rock and dry rock remains very uncertain.

This letter is written to express the hope that some experimenters may be able to carry out investigations underground in a cave, tunnel, or mine which is absolutely devoid of wires or other conductors, and where the windings from the entrance are sufficiently devious to preclude the passage of waves down to the receiver through air.

LA PROPAGATION DES ONDES ELECTROMAGNÉTIQUES (Propagation of electro-magnetic waves).—Com. Metz. (*Q.S.T. Français et Radio Electricité Réunis*, 8, 36 and 37, pp. 63 and 25 respectively.)

A brief historical summary of the work done on wave propagation, reviewing the ideas that are to-day accepted, and their application to the employment of very short waves to meteorology and direction-finding.

EXPÉRIENCES SUR LA PROPAGATION DES ONDES RADIOTÉLÉGRAPHIQUES EN ALTITUDE (Experiments on the propagation of radio waves at an altitude).—P. Idrac and R. Bureau. (*L'Onde Electrique*, 6, 66, June, 1927, pp. 266-267.)

A paper that appeared in *Comptes Rendus*, of 14th March, an abstract of which is to be found in *E.W. & W.E.*, of June, 1927, p. 368.

ATMOSPHERIC ELECTRICITY.

LOI DE DISTRIBUTION DES ORAGES MAGNÉTIQUES ET DE LEURS ELÉMENTS. CONSÉQUENCES À EN TIRER SUR LA CONSTITUTION DU SOLEIL (Law of distribution of magnetic storms and their elements. Inferences to be drawn regarding the composition of the sun).—H. Deslandres. (*Comptes Rendus*, 185, pp. 10-14, 4th July, 1927.)

The author finds that magnetic storms can be divided into groups, in each of which the intervals between the maximum points of the storms, expressed in solar longitudes, are exact multiples of 15 degrees. Successive points of the same storm indicate influxes of electrified particles of different velocity which, emitted at the same time, are deviated by a different angle and separated by the sun's exterior magnetic field. It is as though the corpuscular and even also the undulatory emissions emanated from a deep invisible layer which rotates like a solid body and presents at least 24 permanent volcanoes, of variable activity, distributed uniformly around the axis of rotation. This emitting layer would be the first cause of all the phenomena observed in the sun and what depends on it, and subject at the same time to the great undecennial oscillation. All the magnetic disturbances must therefore be carefully followed during at least one whole period of 11 years. The present article presents an analysis of the eight principal storms of the years 1917, 1918 and 1919, that for the years 1920-1926 having been given previously.

LE CHAMP MAGNÉTIQUE TERRESTRE ET LES PROPRIÉTÉS ELECTROMAGNÉTIQUES INTERNES DU GLOBE (The terrestrial magnetic field and internal electro-magnetic properties of the globe).—M. Brillouin. (*Comptes Rendus*, 184, 13th June, 1927, pp. 1381-1385.)

ON CERTAIN AVERAGE CHARACTERISTICS OF WORLD-WIDE MAGNETIC DISTURBANCE.—S. Chapman. (*Proc. Roy. Soc. A.*, 115, pp. 242-267, July, 1927.)

CURRENTS CARRIED BY POINT-DISCHARGES BENEATH THUNDERCLOUDS AND SHOWERS.—T. W. Wormell. (*Proc. Roy. Soc. A.*, 115, pp. 443-455, July, 1927.)

MÉSURES SUR LES GROS IONS À PARIS.—J. MacLaughlin. (*Comptes Rendus*, 184, 20th June, 1927, pp. 1571-1573.)

Certain results of these observations have already been given (*Comptes Rendus* 184, p. 1183, these abstracts, *E.W. & W.E.*, August, 1927). The present paper summarises some new results concerning the absorption of solar radiation by the ions, their relation to the meteorological elements, and the excess of ions of one sign.

PROPERTIES OF CIRCUITS.

GITTERGLEICHRICHTUNG (Grid rectification).—Y. Groeneveld, B. v.d. Pol, jr., and K. Posthumus. (*Zeits. f. Hochfrequenz.*, 29, 5, pp. 139-147, May, 1927.)

The purely rectifying properties of a triode in the grid rectification circuit-arrangement depend

practically exclusively upon the shape of the grid characteristics and the grid circuit constants. It is shown by means of characteristics that the anode tension has very little influence.

The grid current characteristic is exponential over a wide range, and the inclination of the logarithmic grid-current curve is determined entirely by the temperature. For a given triode the lighting up tension has little influence on this inclination, since the temperature of the emitting part alters little as a percentage.

The increase in grid tension necessary to raise the grid current *e* fold (where *e* is the electronic charge) is called the *temperature tension*.

From the calculation it follows that the rectifying effect is numerically the same for all triodes, if all tensions are expressed in terms of temperature tension: if the rectifying effect is expressed as a percentage of the high frequency tension, then this relation is the same for two triodes with different temperature tensions in the case where two signals are observed that behave like temperature tensions. From this it follows, that for the rectification of weak signals, triodes with small temperature tension are advantageous. Miniwatt valves are therefore to be preferred in this respect to thorium and wolfram valves (bright emitters).

For strong signals the rectifying effect is always about equal to the peak tension of the signal, whatever the type of triode.

LIEFERT EIN ABREISSENDER MODULIERTER UNGEDÄMPFTER SENDER MODULIERTE HOCHFREQUENZ? (Does a modulated I.C.W. transmitter yield modulated high frequency?) —F. Fischer. (*Zeitschr. f. Hochfrequenz.*, 29, 6, pp. 191-194.)

With short waves, it often appears desirable to work, not with an absolutely undamped wave, but with a broader frequency band. In this way the effect of small deviations in the receiver can be eliminated. With beat reception, however, it is not sufficient to modulate the transmitter, since then the heterodyne note always reproduces the variation of the carrier wave or a wave in the side band. Only complete modulation of the transmitter, that can be attained with certainty most simply by working the transmitter with anode alternating current, achieves this end. Then a pure heterodyne note no longer results, the transmitter sounding like a quenched spark transmitter. The theory of this experimental fact is considered here. It is found that a modulated I.C.W. does not in general yield modulated high frequency; beat reception of the complicated oscillation phenomenon that arises producing no heterodyne note, but a noise.

ÜBER SCHWINGUNGSERZEUGUNG MITTELS ELEKTRONENRÖHREN-SYSTEMEN, WELCHE SELBSTINDUKTION NICHT ENTHALTEN (On the generation of oscillation by valve systems containing no self-inductance).—K. Heegner. (*Zeitschr. f. Hochfrequenz.*, 29, 5, May, 1927, pp. 151-154.)

The manner of working of the "multivibrator" (Abraham and Bloch, *Ann. de Physique*, 1919, p. 237) is discussed, and the instability of the direct current state is represented by a diverging infinite series. The influence of capacities connected in parallel with the anode resistances is more closely investigated. It is shown that the self-excited oscillation can be adjusted to any desired back-coupling, but also that it is possible for the amplitude to vanish or jump to a finite value, depending on the grid potential. The theory of the coupling of the system is developed and it is shown that this fails on the general theory when the coupling is loose. A geometrical construction, given earlier, is described more exactly.

L'AMPLIFICATION À RÉSONANCE AVEC LES BIGRILLES (Resonance amplification with four-electrode valves).—R. Barthélémy. (*L'Onde Electrique*, 6, 64, pp. 152-160.)

The author explains the employment of four-electrode valves to avoid undesired reaction in resonance amplifiers, making a series of stages of high-frequency amplification easily possible.

UNE MÉTHODE SIMPLE DE CALCUL DE L'INDUCTANCE DE MODULATION (A simple method of calculating the modulation inductance).—C. Krulisz. (*L'Onde Electrique*, 6, 66, pp. 255-262, June, 1927.)

The author shows the effect of different factors on the modulation obtained by means of a "constant current" system. Given the fidelity of reproduction to be attained, he deduces a simple formula for determining the modulation inductance.

GRID SIGNAL CHARACTERISTICS AND OTHER AIDS TO THE NUMERICAL SOLUTION OF GRID RECTIFICATION PROBLEMS.—PART I.—W. Barclay. (*E.W. & W.E.*, August, 1927, pp. 459-466.)

UNTERSUCHUNG EINES SCHWINGUNGSKREISES MIT EISENKERNSPULE BEI GERINGER SÄTTIGUNG DES EISENS (Investigation of an oscillatory circuit with an iron-cored coil, the iron being feebly saturated.)—H. Winter-Günther. *Zeitschr. f. Hochfrequenz.*, 29, 5, pp. 148-150, May, 1927.)

DREI DEMONSTRATIONSVERSUCHE AUF DEM GEBIETE DER SCHWINGUNGSTECHNIK (Three demonstration experiments in the range of oscillation technique).—H. Sell. (*Zeits. f. techn. Physik*, 8, 6, pp. 222-230.)

The demonstrations described concern :—

1. A mechanical electrical analogy of the "pull" phenomena in coupled oscillatory circuits.

2. The sound nozzle as a highly sensitive method of electrical measurement.

3. Experiments on the vibration of light membranes.

TRANSMISSION.

ON THE CONSTANTS OF RECEIVING AND TRANSMITTING ANTENNÆ.—R. Wilmotte. (*Philosophical Magazine*, 4, 20, pp. 78-91, July, 1927.)

It is found theoretically that, if the distribution of the constants of an antenna is the same for

transmission as for reception, the effective resistance, reactance, and the effective height are also the same in the two cases. The radiation resistance, however, is slightly different.

Experimental evidence down to about 100 metres wavelength showed that the difference in the reactance in the two cases was undetectable, while there was strong evidence that there was a small difference in the resistance, that for reception being slightly greater than that for transmission.

DER GEGENTAKT-RÖHRENGENERATOR FÜR MODULIERTE SCHWINGUNGEN (The "push-pull" valve generator for modulated oscillations.) —P. Schmakow. (*Zeitschrif. Hochfrequenz.*, 29, 6, pp. 171-177.)

The fundamental circuit of the push-pull modulating system requires one oscillation and two speech valves. This paper describes a circuit-arrangement which combines the speech and oscillation adjustments and requires only two valves. The paper considers :—

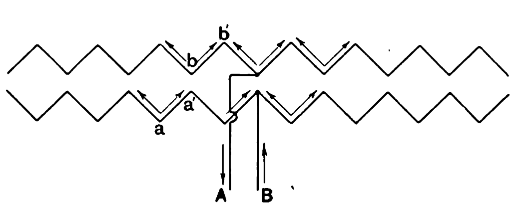
1. The working principle of a two-valve push-pull generator for modulated oscillations.

2. The graphical method of the grid modulating principle ; the conditions for undistorted modulation are that the no-load current must be a quarter of the saturation current and the note frequency curve must lie in the region of negative grid potential.

3. The graphical method of the push-pull modulating principle ; the conditions for undistorted modulation are given for different no-load cases, distortion occurring when the note frequency curve encroaches into the region of positive grid potential.

NOUVELLE ANTENNE DIRECTIVE SIMPLE POUR ONDES COURTES (New simple directional antenna for short waves).—H. Chireix. *Q.S.T. Francais et Radio Electricité Réunis*, 8, 37, pp. 43-46.)

In the Bulletin Technique of *Radio Electricité*, 25th July, 1924, the author investigated combinations of transverse and longitudinal alignments and recalls here the practical conclusions drawn. Further consideration has led to the development of a new alignment of antennæ in phase, shown diagrammatically below.



An element such as *aa'*, *bb'* constitutes an antenna of one complete wavelength comprising two doublets of the same sign having the effect of increasing the directivity in the plane of the zenith. This system has been employed for communication between France and the Argentine on a wave of 14 metres 50 with favourable results.

A PROPOS DE L'ANTENNE DE HERTZ (Concerning the Hertz antenna).—J. Balta Elias. (*L'Onde Electrique*, 6, 64, pp. 173-177.)

Since for the transmission of short waves linear antennæ are now frequently employed, without earth, operating in a way that recalls the Hertz oscillator, the author here gives the results of experiments he made last year with a view to clearing up some obscure points in the functioning of these antennæ.

SUR LES OSCILLATIONS DE BARKHAUSEN OBTENUES AVEC DES LAMPES FRANÇAISES (On the Barkhausen oscillations obtained with French valves).—E. Pierret. (*Comptes Rendus*, 184, 13th June, 1927, pp. 1428-1430.)

Description of experiments with wavelengths mostly less than 50 centimetres when certain anomalies were observed which are enumerated here.

SHORT-WAVE TRANSMISSIONS.—*Wireless World*, 29th June, 1927, p. 816.

A list of stations in all parts of the world which transmit fairly regularly on short waves.

RECEPTION.

THE PERFORMANCE OF AN INTERMEDIATE FREQUENCY AMPLIFIER.—M. Scroggie. (*Journ. Inst. Elect. Engineers*, 65, pp. 644-647, June, 1927.)

The paper gives the results of measurements carried out on an intermediate-frequency amplifier forming part of a commercial supersonic heterodyne receiver designed for broadcast reception. The amplifier is described, with special reference to the coupling transformers. Slight modifications of the circuit are necessitated by the method of test, but it is concluded that the conditions of measurement approximate closely to those of normal use.

Three representative types of valves are employed in turn and it is shown that, for a prescribed standard of cut-off at the extremes of the side-bands, the amplification obtainable increases with the mutual inductance of the valves. The best type of valve to use in various circumstances is deduced from the results obtained.

ÜBER DIE EINEM EMPFÄNGER DURCH ERDUNG ZUGEFÜHRTE ENERGIE (On the energy conducted to a receiver through the earthing). —A. Szekely. (*Zeitschr. f. Hochfrequenz.*, 29, 5, May, 1927, pp. 155-158.)

Measurements are described which show that fluctuating tensions are introduced into a receiving circuit, that do not enter by way of the antenna, but through the earth connection. The measurements were carried out not far from the transmitter, and it remains to be discovered whether at greater distances as well the conduction of energy through the earth connection is still noticeable compared with the arrival *via* the antenna, which the author was prevented from investigating for want of a suitable receiver.

To explain the observations described, the view is expressed that the energy introduced through the earth connection arises from the ground field which

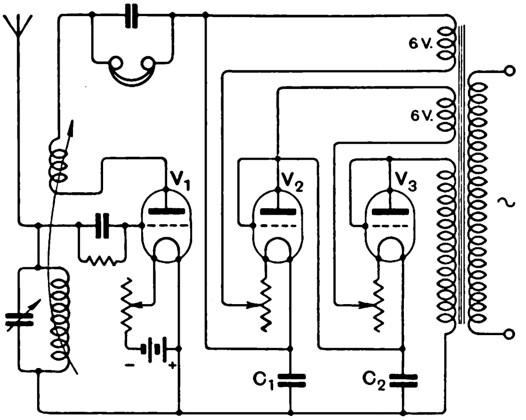
sets the buried earth leads in stationary oscillation. This view is supported by the marked variation of the energy arriving through the earth connection. If this view is correct, care will have to be exercised in interpreting the variations of signal strength with earthed receivers, for distinction will have to be drawn between variations due to change of the atmospheric field and those caused by change of the ground field.

NACHTRAG ZU DER ARBEIT: "EIN BEITRAG ZUR THEORIE DER NIEDERFREQUENZ—VERSTARKUNG MIT WIDERSTANDSKOPPLUNG" (Supplement to the paper: "A contribution to the theory of low-frequency amplification with resistance coupling").—H. Kafka. (*Zeitschr. f. Hochfrequenz.*, 29, 6, p. 190.)

In the above paper (*Zeitschr. f. Hochfrequenz.*, February, 1927, these abstracts, *E.W. & W.E.*, May, 1927, p. 308) the frequency dependence of the amplification ratio $\mathcal{E}_{g_1}/E_{g_1}$ of a stage of amplification with resistance-capacity coupling, taking account of the valve capacities, is represented by a locus diagram. It is shown here that the influence of the coupling can be brought out still more clearly by examining the ratio $\mathcal{E}_{g_2}/(E_{g_1}/D_1)$, instead of the ratio $\mathcal{E}_{g_2}/E_{g_1}$. As the frequency varies, the ends of the vector $\mathcal{E}_{g_2}/(E_{g_1}/D_1)$ describe a circle passing through the origin with its centre on the negative effective axis. The diameter of this circle, the formula for which is given, determines the maximum value that the amplification ratio $\mathcal{E}_{g_2}/(E_{g_1}/D_1)$ can assume.

FILTRE THERMOIONIQUE POUR L'ALIMENTATION D'UN RÉCEPTEUR SUR SECTEUR ALTERNATIF (Thermionic filter for supplying a receiver from the mains). — E. Fromy. (*L'Onde Electrique*, 6, 64, pp. 161-167.)

A thermionic valve possesses the property of becoming saturated: when the anode tension



reaches a certain value the current emitted remains strictly constant whatever the tension of the plate. This property can be utilised to control the output of a source of undulating E.M.F. or limit the current to a given value, the only condition being that at no moment the anode tension falls below the value corresponding to saturation. Under these circumstances a valve can play the part of an infinite impedance and be utilised whenever choke coils are ordinarily employed or low-pass filters consisting of inductance and capacity, and in particular, it can be used as filter for supplying a receiver from the mains, the circuit-arrangement being shown in the diagram inset.

Such a thermionic filter can also be used to modulate a transmitter by the constant current method, the circuit-diagram for which is also given.

RESISTANCE-CAPACITY AMPLIFICATION.—W. James. (*Wireless World*, 6th, 13th and 20th July, 1927.)

An article in three parts dealing respectively with: anode circuit conditions and the calculation of voltage amplification, the calculation of coupling condensers and grid-leak values, and stray capacities and their effect on the performance of resistance amplifiers.

SCREENED VALVES.—P. Willans. (*Wireless World*, 27th July, 1927, pp. 107-110.)

Description of a receiving system employing valves which may render unnecessary external neutralisation in H.F. circuits.

PROCÉDÉ D'ELIMINATION DE L'INFLUENCE, À LA RÉCEPTION, DES VARIATIONS DE FRÉQUENCE D'UN POST D'EMISSION À ONDES COURTES (Method of eliminating the effect at the receiver of frequency variations in a short wave transmitting station). — M. Veaux (*L'Onde Electrique*, 6, 66, pp. 263-265, June, 1927.)

SPECTRE DE HAUTE FREQUENCE ET DEFORMATION (High frequency spectrum and distortion).—R. Henon. (*Q.S.T. Français et Radio Electricité Réunis*, 8, 37, pp. 8-16.)

SUR LE CONTACT MÉTAL-SULFURE CUIVREUX (On the metal-cuprous sulphide contact).—J. Cayrel. (*Comptes Rendus*, 185, pp. 46-48, 4th July, 1927.)

The electric applications of imperfect contacts have led them to be considered under the triple aspect of coherers, rectifying detectors, and oscillation generators (Lossev effect). Results are given here establishing a connection between these different aspects and confirming the view of M. Blanc (*thèse*, 1905) as to the relationship between coherers and detectors. They show that:

1. The inversion of the rectification in the case of the contact metal-Cu_2S is due to a unilateral coherence of the contact.

2. This coherence is nothing but the fall of resistance utilised in the case of generating contacts to make d_v/dI negative.

3. The anti-coherence of the contact resistance in the sense metal-Cu_2S differs from the anti-coherences observed by M. Blanc with the aluminium-steel contact only by its discontinuous character and enormous magnitude.

F. SEIDEL'S "SELBSTTÖNENDER KRISTALL" (F. Seidel's "spontaneously oscillating crystal"). —K. Lichtenecker. (*Zeits. f. techn. Physik*, 8, 4, pp. 161-163.)

According to F. Seidel (*Phys. Zeitschr.*, 27, 64 and 816) a metal-crystal contact in the circuit of the singing arc is able to give a continuous characteristic note.

The present article shows that the phenomenon is not due to the electro-magnetic oscillations but to the steep temperature gradient occurring at the metal point.

VALVES AND THERMIONICS.

ÜBER RÖHRENVERZERRUNGEN BEI VERSTÄRKERN (Distortion in amplifiers due to the valve).— M. von Ardenne. (*Zeits. f. Techn. Physik*, 8, 6, pp. 235-239.)

Investigation of distortion of the amplitude arising from the curvature of the working characteristic of a valve. Attempt is made to comprehend quantitatively the relation between distortion and input tension and between the curvature of the working characteristic and the resistance in the anode circuit.

DER CHARAKTEROGRAPH UND DIE DYNAMISCHEN CHARAKTERISTIKEN EINER ELEKTRONENRÖHRE (The characterograph and the dynamic characteristics of a valve).—B. Ostroumoff. (*Zeits. f. Techn. Physik*, 8, 4, pp. 163-164.)

Description of apparatus for obtaining automatically electrical characteristics and a method of recording the dynamic characteristics of a valve. Specimen results are shown.

LA LAMPE À DEUX GRILLES (The four-electrode valve).—M. Chauvierre. (*Q.S.T. Français et Radio Electricité Réunis*, 8; 37, 38 and 39; pp. 17, 38 and 68 respectively.)

THE K.L.1 VALVE.— F. E. Henderson. (*Wireless World*, 20th July, 1927, pp. 83-85.)

Constructional details and photographs are given and the advantages of indirectly heated cathode valves explained.

ELECTRON EMISSION FROM THORIATED TUNGSTEN —S. Dushman and J. Ewald. (*Physical Review*, 29, 6, pp. 857-870, June, 1927.)

The following abstract is given :—

Constants of the electron emission from a monatomic layer of thorium on tungsten at temperatures from 1,000 *degrees to* 2,000 *degrees K.*—The electron emission for a monatomic layer of thorium on tungsten is best represented for zero field strength by the relation $I=3T^2\epsilon^{-30{,}500/T}$, where I is expressed in amps./cm². The emission was measured for different states of activation of the filament. If we let θ be the fraction of surface covered with thorium, then for $\theta < 0.95$ (approx.) log A_θ varies linearly with b_θ when the emission for the given surface is represented by

$$I=A_\theta T^2\epsilon^{-b_\theta/T}$$

It is also pointed out that the emission for a monatomic film of thorium on tungsten is greater than that observed for metallic thorium.

THE CHARACTERISTICS OF TUNGSTEN FILAMENTS AS FUNCTIONS OF TEMPERATURE.—Part II. —H. A. Jones and I. Langmuir. (*General Electric Review*, 30, 7, pp. 354-361, July, 1927.)

Continuation of an article begun in the previous number of the Review, giving the most recent data on the characteristics of tungsten filaments in vacuo at various temperatures.

MEASUREMENTS AND STANDARDS

THE HIGH FREQUENCY RESISTANCE OF A BUREAU OF STANDARDS TYPE VARIABLE AIR CONDENSER.—S. Brown, C. Wiebusch and M. Colby. (*Physical Review*, 29, 6, pp. 887-891, June, 1927.)

A method is described whereby the high frequency resistance of variable air condensers is measured with an accuracy of 1 per cent. Data are given showing the resistance of a Bureau of Standards type 0.0035μμF condenser at wavelengths from 40 to 175 metres and at different positions on the scale. The values obtained range from 0.0283 ohms at 119 metres and 174 degrees scale setting (range 0 degree to 180 degrees), to 0.150 ohms at 63 metres and 20 degrees condenser setting. The resistance increases rapidly towards the lower positions on the scale, and also increases with wavelength. The calculated values of the high frequency resistance of large conductors were checked experimentally.

THE "LAW CORRECTION" OF VARIABLE AIR CONDENSERS.—W. Griffiths. (*E.W. & W.E.*, August, 1927, pp. 479-488.)

DETERMINING THE EXTREMUM SCALAR VALUE OF A COMPLEX QUANTITY.—H. Boyland. (*Electrician*, 24th June, 1927, p. 703.)

In a paper published in the *Proc. Inst. Radio Engineers*, for October, 1926, Mr. Roberts describes a method of determining an extremum of a complex quantity when the variable is either a pure real or pure imaginary quantity. The present article extends the method to the case in which the variable occurs both in the real and imaginary parts of the expression.

ÜBER MESSUNGEN AN PIEZO-ELEKTRISCHEN KRISTALLEN (Measurements on piezo-electric crystals).—K. Heegner. (*Zeitschr. f. Hochfrequenz.*, 29, 6, pp. 177-180.)

A method of recording the resonance curves of piezo-electric crystals is described and the dependence of the damping of an oscillating crystal upon mechanical and electrical influences investigated. A method of finding the coupling of a crystal is given together with observations on the "Ziehen" phenomenon.

DÉFORMATIONS ELECTRIQUES DU QUARTZ (Electric deformations of quartz).—M. Ny Tsi Ze. (*Comptes Rendus*, 184, 27th June, 1927, pp. 1645-1647.)

Description of an attempt to measure directly the small deformations of quartz under the influence

of an electric field by the method of light interference. The experimental arrangement is analogous to that of Fizeau in which the relative displacement is observed between a fixed surface and one subject to the displacement under investigation.

Formulæ are given for the deformations in the three directions (normal to optic and electric axes, in direction of electric axis and in that of optic axis) and some idea of the magnitude of the phenomena. It is probably to the purely dielectric deformation in the direction of the optic axis that one must ascribe the third natural frequency of resonant quartz (Hund, *Proc. Inst. Radio Eng.*, 14, p. 447, Aug., 1926).

The deformations of quartz appear to be instantaneous and devoid of hypteresis and are very regular.

Circuit Electrique Equivalant à un Quartz Piezo-Électrique (Electrical circuit equivalent of piezo-electric quartz).—F. Bedeau. (*Q.S.T. Français et Radio Electricité Réunis*, 8, 37, pp. 22-24.)

It is shown how by simplifying the elemental circuit (leaving out the resistance) very simple calculation makes it possible to recover the two chief peculiarities observed by Cady, namely the existence of a negative capacity and a crevasse in the resonance curve.

A Simple Indirect Method of Measuring Grid Current.—(*E.W. & W.E.*, August, 1927, pp. 457-458.)

Explanation of von Ardenne's method of measuring very small grid currents described in the March number of the *Zeitschr. für Hochfrequenz.*

Das Empfangs — Überwachungsgerät der Reichs—Rundfunk—Gesellschaft (The imperial broadcast society's instrument for checking reception).—W. Reisser. (*Elektrische Nachrichten-Technik*, 4, 5, May, 1927, pp. 225-227.)

A brief description of the apparatus is given with circuit diagrams.

Eine Schallregistriervorrichtung zur Aufnahme der Frequenzkurven von Telephonen und Lautsprechern (A sound-registering apparatus for recording the frequency curves of telephones and loud-speakers.)—M. Grützmacher and E. Meyer. (*Elektrische Nachrichten-Technik*, 4, 5, May, 1927, pp. 203-211.)

Description of an instrument for recording the frequency curves of telephones and loud-speakers having the necessary requirement of a rectilinear frequency curve. The apparatus consists essentially of a condenser-microphone in a high frequency arrangement that can be calibrated acoustically in absolute measure by entirely electric means after a new method. A high frequency heterodyne buzzer is used as current generator with the continual change of frequency necessary for registration. Photographically recorded frequency curves of telephones and loud-speakers serve as examples. For investigating the frequency relation of the condenser microphone itself, experiments are arranged in vacuo; thereto the frequency curves of the condenser microphone with different pressures are recorded and the corresponding vibration figures of the membrane obtained.

Some Recent Advances in Alternating Current Measuring Instruments.—K. Edgcumbe and F. Ockenden. (*Journ. Inst. Elect. Engineers*, 65, pp. 553-599, June, 1927.)

The full text of the paper read before the Institution, 3rd February, 1927, with the discussion afterwards.

Abstracts of the paper appeared in the *Electrician* and *Electrical Review*, of 11th February.

Messung des Widerstandes von Stromzweigen bei Durchgang von hochfrequentem Wechselstrom (Measurement of the resistance of current branches when traversed by high frequency alternating current).—H. Bruun. (*Elektrische Nachrichten-Technik*, 4, 5, May, 1927, pp. 218-225.)

Absorption Wavemeter.—H. Dent. (*Wireless World*, 29th June, 1927, pp. 829-832.)

Description of an absorption wavemeter for use on all wavelengths between 14 and 200 metres.

SUBSIDIARY APPARATUS.

Sur une Disposition de Cage de Faraday pour Radiotelegraphie (On a Faraday Cage Arrangement for W.T.).—MM. Beauvais and Mesny. (*Comptes Rendus*, 184, 20th June, 1927, pp. 1546-1547.)

With the usual type of Faraday cage it is often impossible to prevent the escape of electro-magnetic waves through the crack of the door closing the cage, also however well the door fits, the metal of the cage and that of the door mutually offer a certain contact resistance, which modifies the free passage of high frequency currents round the sides of the cage, and consequently the balance is disturbed. To remedy this the authors have designed a cage consisting of a box made of plates of metal carefully soldered, with the lid fitting into a groove in the upper part of the box: by making the sides of the groove and the lid with an amalgamated metal, and filling the groove with mercury, simply putting on the lid will secure a perfect joint through which no waves can pass.

Neutralisation of the Deflecting Field in a Braun Tube with External Electrodes.—L. Jones and A. Cravath. (*Physical Review*, 29, 6, pp. 871-879.)

The field of the external electrodes is rapidly neutralised by the collection of ions and electrons on the tube walls so that the deflection is not simply proportional to the applied voltage. The neutralisation proceeds like the discharge of a condenser through a resistance for which the time constant is $RC=T$. This time constant T, which is a reciprocal measure of the rate of neutralisation, was both calculated and measured directly. The deflection of the beam is found as a function of T and the applied voltage, and the expressions for amplitude

and phase of deflection for sinusoidal applied voltage are derived, the results being

$$D = V_0 S \cos \delta \sin (2 \pi f t + \delta)$$
$$\delta = \cot^{-1} 2 \pi f T$$

where D is beam deflection, V_0 the applied voltage, f the frequency, and S is a constant of the tube.

Battery Eliminators, or Appliances for the Operation of Radio Receiving Apparatus by Energy derived from Electric Supply Mains.—P. Coursey and H. Andrewes. (*Journ. Inst. Elect. Engineers*, 65, pp. 705-726, July, 1927.)

The full text of the paper, read before the Wireless Section, 6th April, abstracts of which have already appeared.

The Hot-Wire Microphone and Audio-Resonant Selection.—G. Blake. (*E.W. & W.E.*, August, 1927, pp. 493-501.)

Paper read before the R.S.G.B., 25th May, 1927.

H.T. from the Mains.—H. Kirke. (*Wireless World*, 22nd June, 1927, pp. 779-783.)

Some notes on mains units and their application to receivers.

Gramophone Pick-up Devices.—G. Sutton. (*Wireless World*, 20th June, 1927, pp. 66-68.)

Description of method of comparing loud-speakers with the aid of the gramophone.

Loud-Speaker Inefficiency. — N. McLachlan. (*Wireless World*, 6th July, 1927, pp. 11-14.)

An account of sources of energy loss which reduce efficiency to 1 per cent.

GENERAL PHYSICAL ARTICLES.

Über die Richtwirkung von Schallstrahlern (On the directivity of sound radiators).—H. Stenzel. (*Elekt. Nachr.-Technik*, 4, 6, pp. 239-253, June, 1927.)

Mathematical investigation of the directivity of the sound coming from a series of point sources, passing on to a calculation of the directivity of the radiation from a source of sound that can no longer be considered small compared with the wavelength, by regarding it as composed of an infinite number of point sources.

On the Propagation of Sound in the General Bessel Horn of Infinite Length.—(*Journal Franklin Institute*, June, 1927, pp. 849-853.)

Discussion by Mr. Hanna of Mr. Ballantine's paper published in this journal of January, 1927, p. 85, followed by a reply from Mr. Ballantine.

Die Lautstärke von zusammengesetzten Tönen und Geräuschen (The intensity of composite notes and noises).—H. Barkhausen and H. Tischner. (*Zeits. f. Techn. Physik*, 8, 6, pp. 215-221.)

Kathodenzerstäubung (Cathode sputtering).—A. Güntherschulze. (*Zeits. f. Techn. Physik*, 8, 5, pp. 169-178.)

Ionisation by Collisions of the Second Kind in Mixtures of Hydrogen and Nitrogen with the Rare Gases.—G. Harnwell. (*Physical Review*, 29, 6, pp. 830-842, June, 1927.)

Two main conclusions are drawn from the experiments: firstly, that at a certain number of collisions between an atomic or a molecular ion and an atom or ion of lower ionising potential an electron transfer will occur, and secondly, the probability that a given transfer will occur is an inverse function of the difference between the ionising potentials involved.

What is Electricity?—W. M. Thorton. (*Journ. Inst. Elect. Engineers*, 65, pp. 674-680.)

The full text of the third Faraday lecture, delivered before the Institution 17th March, abstracts of which have already appeared. The lecture is divided into the following three parts:—

Evidence that the two units of electricity have the nature of screws or twists.

Evidence of how such screws came into being.

How they combine to form matter and by their vibrations give rise to the electrical radiation we know as light and heat.

STATIONS: DESIGN AND OPERATION.

Another Beam Service Opened. (*Electrician*, 8th July, 1927, p. 62.)

A direct wireless telegraphic service between London and Cape Town was inaugurated on 4th July. This is the third group of beam stations to be completed for direct communication with the Dominions, the beam services with Canada and Australia being already in operation. The fourth and last group of the Imperial Wireless Beam Chain will be completed next month, when the service with India will be opened. The stations for South African communication are the first to have actually in operation the principle of using two wavelengths, one for daylight and the other for night communication, the exact wavelengths of the English transmitting station being 16.146 and 34.013 metres, and those of the South African station 16.077 and 33.708 metres. It is estimated by the Marconi Company that the stations are capable of handling about 160,000 words per day in each direction, and the service is able to deal expeditiously with all available traffic between South Africa and England.

The *Electrical Review* of 8th July also gives details of the service with illustrations of the equipment.

Daventry Junior.—H. Kirke. (*Wireless World*, 20th July, 1927, pp. 69-70.)

Technical details of this new high-power transmitter are given with illustrations.

Alterations to the Modulating Panel at 2LO.—E. Green, J. Hewitt and T. Petersen. (*E.W. & W.E.*, August, 1927, pp. 467-488.)

MISCELLANEOUS.

SOUTH AFRICA—SINGLE MANAGEMENT—(*Electrical Review*, 24th June, 1927, p. 1021.)

The recently-formed South African Broadcasting Co., after having taken over and resuscitated the Johannesburg station, has since also purchased the Cape Town station and entered into an agreement with the Durban Town Council to take over its station. With all the South African broadcasting stations now under one management, it is intended to interconnect them all with land lines and take full advantage of relaying. The new company, being also interested in the African Theatres Trust, intends to transmit items from various theatres with greater variety of artistes than there is under present arrangements.

THE ORGANISATION AND PROBLEMS OF NATIONAL BROADCASTING.—A. N. Goldsmith. (*General Electric Review*, 30, 7, pp. 349-353, July, 1927.)

THE DISTRIBUTION OF BROADCASTING STATIONS. —P. P. Eckersley. (*Wireless World*, 13th July, 1927, pp. 32-35.)

MAKING SYNTHETIC GALENA.—G. Tatham. (*Wireless World*, 22nd June, 1927, pp. 774-778.)

D. E. H.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto - Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

SENDADO.

ŜANĜOJ AL LA MODULA PANELO ĈE 2LO.—E. Green, J. L. Hewitt, and T. G. Petersen.

La artikolo priskribas eksperimentojn faritajn je la sendilo ĉe la originala 2LO, kun celo atingi konstantecon de modulado je ĉiuj modulaj frekvencoj, la evoluoj efektivigitaj estante enkorpigitaj en la posta Londona Stacio.

La sendilajn cirkvitojn oni montras plene kaj konsideras skeletoforme, dum oni utiligas la anodvoltajn—anodkurentajn karakterizojn (jam antaŭe diskutitaj de unu el la aŭtoroj en *E.W. & W.E.*, Julio kaj Aŭgusto, 1926a), por montrila funkciajn kondiĉojn de la valvoj je diversaj modulaj frekvencoj. Oni desegnis novan tipon de modula valvo, kapablanta pligrandan dispeliĝon, kaj similaj kurvoj estas montritaj por ĉi tiu tipo, kun diskutado pri la plibonigoj efektivigotaj kaj pri ŝanĝoj al la sub-modulatora panelo.

Du aldonoj sekvas, la unua traktanta pri kalkulado de la Funkciaj Elipsoj por la diversaj okazoj, kaj la dua pri la Potencaj Interrilatoj en la Oscilatora kaj Modulatora cirkvitoj, kiam oni uzas ŝokbobenan kontroladon.

RICEVADO.

LA VARMFADENA MIKROFONO KAJ AŬD-RESONANCA SELEKTADO.—Raporto de Prelego legita de S-ro. G. G. Blake, M.I.E.E., A.Inst.P., ĉe la Radio-Societo de Granda Britujo, je 25a Majo, 1927a.

La lekcianto prezentis la temon per priskribo pri fruaj aplikadoj de la varmfadena principo, aparte rilate al sono, kaj pri la *Tucker* varmfadena mikrofono kaj ĝia utiligado je milita sonkalkulado. Oni faris longan aludon al la artikolo de D-ro. H. E. Watson pri la temo en *E.W. & W.E.*, de Marto, 1927a.

La aŭtoro poste priskribis siajn proprajn eksperimentojn kiel daŭrigo pri la temo, inkluzive la priskribo de resonatoroj de diversaj konstantoj, kiuj estas cititaj. Oni demonstraciis pri la utiligo de la varmfadena mikrofono kiel malhelpilo de interfero. Eksteraj signaloj, influitaj de multa interfero produktita de la lekcianto, estis selektitaj pere de la resonanca mikrofono, kaj ilia ricevado, libera je ĝeno, montrita sur registrilo. La aŭtoro finis, sugestante pluajn aplikadojn de la varmfadena mikrofono je ricevado.

Raporto pri la diskutado, kiu sekvis la prelegon, estas ankaŭ presita.

KRAD-SIGNALAJ KARAKTERIZOJ KAJ ALIAJ HELPOJ JE LA NUMERA SOLVO DE KRAD-REKTIFAJ PROBLEMOJ.—W. A. Barclay.

Post mallonga konsiderado pri la principoj de krada rektifado, la aŭtoro skizas la ordinaran diagramon de kradkurenta karakterizo, kaj tiam disvolvas pluan kurvon montrantan, kiel krada kurento varias dum signala tensio E estas impresita sur la kradon de diversaj mezaj kradaj potencialoj. Ĉi tiun novan kurvon li priskribas kiel la kradan signalan karakterizon por signala amplitudo E.

Li poste disvolvas ĝeneralan esprimon por krada kurento en la ĉeesto de signalo, kaj ilustras kaj geometriajn kaj aritmetajn metodojn por deternini la kradsignalan karakterizan kurvon. La metodoj estas ilustritaj per aparta aplikado al serio de kradsignalaj karakterizoj por valvo de difinita tipo

La artikolo estas daŭrigota.

MEZOROJ KAJ NORMOJ.

SIMPLA NEREKTA METODO MEZURI KRADAN KURENTON.

Redakcia noto pritraktanta metodon—ŝulditan al von Ardenne—per kio, kradkurentoj de 10^{-10} aŭ 10^{-9} amperoj estas mezureblaj. La metodo

estas bazita sur la fakto ke, se krada rezistanco de konata valoro estas uzita, la kradkurento kaŭzas falon de potencialo laŭ la elflua rezisteco, kaj tiel ŝanĝos la kradan potencialon per kvanto determinebla per la ŝanĝo de anoda kurento produktita.

La principoj de la metodo estas diskutitaj kaj ekzempleroj donitaj, la metodo montrita donante mezurojn de proksimume 2×10^{-9} amperoj.

HELPA APARATO.

La "Leĝo-Korektado" de Varieblaj Aeraj Kondensatoroj.—W. H. F. Griffiths.

Ĉi tiu artikolo estas plua kontribuaĵo de la aŭtoro pri la temo de la leĝoj de varieblaj kondensatoroj. Ĝi traktas aparte pri la efekto ĉe la "leĝo de plata rotacio" de la minimuma aŭ restanta kapacito de la finita kondensatoro, kiel pliigita per la kapacito de la cirkvito, de kio ĝi estas parto. Komerca ekzemplo de la leĝo-korekteco estas ilustrita en la okazo de komerce produktita Rektlinia Frekvenca Kondensatoro, kun diskutado pri eraroj kaj foriroj for de la rektlinia leĝo. Metodoj por korekti la Rektlinian Leĝon (por la Rektlinia Frekvenca ekzemplo) estas poste pritraktitaj, inkluzive la limigo de skalo de alĝustigo enkondukita per la metodo de korektado. La diskutado estas bone ilustrita per kurvoj de eksperimentoj kaj kalkulitaj rezultoj.

La korektado de Rektliniaj Ondolongaj Kondensatoroj estas poste diskutitaj, kun pluaj kurvoj por leĝo-korektado.

La aŭtoro konkludas, ke estas plibone utiligi varieblajn kondensatorojn kun konstantaj kapacitaj skaloj, kie ekzakta konformeco al leĝo estas absolute necesa.

DIVERSAĴOJ.

Resumoj kaj Aludoj.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienco kaj Industria Esplorado.

Matematiko por Senfadenaj Amatoroj.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto komencas la konsideradon pri la Diferenciala kaj Integrala Kalkuluso, traktante pri la celo kaj amplekso de la diferenciala kalkuluso, proporcio de ŝanĝo, ĝenerala difino de diferenciala koeficiento, geometria interpretado de diferenciala koeficiento, la signo de la diferenciala koeficiento, kaj la diferencigo de pozitivaj potencoj de X.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

Television.

To the Editor, E.W. & W.E.

Sir,—Though Dr. von Mihaly's book* contains very full descriptions of the television apparatus which he has invented and named the "Telehor," one finds only a very few words as to results obtained with it. He tells us (p. 100 and p. 147) that with the first model he succeeded in transmitting some simple geometrical figures, white on a black ground, artificially illuminated, but the reception was not quite satisfactory, and he was "depressed (*missgestimmt*) by the bad results." With the later model (p. 157) "the transmissions were scarcely any better than the previous ones." He ascribes this lack of success to instrumental deficiencies which he hopes to improve.

With great diffidence, I venture to point out an extraordinary oversight which the inventor appears to me to have made in planning the optical part of the transmitter, and which would amply account for failure, even given perfection in all other respects.

The following is the plan adopted. By means of a powerful lens-system, a very small real image of the object is thrown upon the minute *plane* mirror of an oscillograph. This mirror (in its mean position) is at 45° to the optic axis, and therefore the beam of light, after forming the image, is deflected through a right angle. After travelling some distance it strikes a thin opaque screen, some 10 cm. wide, with a hole 1 mm. square at its centre, covering a selenium or photo-electric cell. The beam forms a luminous patch on the screen. The mirror oscillates, with two synchronised movements of rotation of very different frequencies, about two perpendicular axes, horizontal and vertical. Hence the reflected patch of light travels across the screen rapidly in zigzag fashion, so that every element of it in turn comes over the hole, and acts on the cell.

The oversight referred to consists in assuming that this out-of-focus patch of light on the screen is a true picture of the object, which, of course, is not the case. And, naturally, if the picture transmitted is faulty one cannot expect good reception. The error occurs three times over, both in text and diagrams, differently expressed each time (pp. 101-2, 106, 158; Figs. 66, 69, 96).

It may be remarked that there is no lens between mirror and screen, and the description of the mirror (p. 162) clearly implies that it is plane: "a thin glass plate, silvered, 3×3 mm., area 9 mm." A plane mirror has no effect on the convergence or divergence of rays, but merely deflects the beam as a whole.

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* *Das elektrische Fernsehen und das Telehor*, by Dénes von Mihaly, M. Krayn, Berlin, 1926.

Only at the proper focus is there point for point correspondence between object and image (and not always there !). At any other distance a point in the object would be represented on a screen, not by a point, but by a blurred oval patch. Neighbouring points in the object would be represented by overlapping patches, so that not only outlines, but gradations of light and shade would be mixed and confused.

The trouble no doubt was that if the experimenter focused the image upon the screen over the cell, then the minute mirror could only intercept a very small portion of the wide beam necessary to give a fair-sized picture, and most of the light would pass straight on, instead of being reflected to the cell.

If the mirror was concave some sort of enlarged picture could be formed on the screen by focusing the previous image yielded by the lens-system, not *on* the mirror as the description states, but some distance in front of it, outside its focus. It may be remarked, however, that a concave mirror gives a very unsatisfactory picture of an extended object. In the case of a fixed mirror, compensatory errors might be introduced into the accompanying lens-system, but here the oscillation would upset the calculations.

Another practical difficulty presents itself. In the nature of the case the mirror must be very light, and we are told that it is made of skin-thin glass—microscope-slide cover glass. It is extremely doubtful whether such a fragile article could stand the manipulation necessary to produce an optically perfect surface, or even if so, could retain its form. Temperature changes, pressure of supports, etc., would affect it. The usual function of a galvanometer or oscillograph mirror is merely to reflect a small spot of light, a very different matter from yielding a detailed picture.

At the receiving station Dr. von Mihaly employs another oscillograph, similar to, and synchronised with, the one at the transmitting station, to reflect the concentrated light of a Pointolite (or similar) lamp upon a screen. The small illuminated patch on the screen traces very rapidly a zigzag (or, more strictly, sine curve) path, the intensity of illumination of the patch at any moment being regulated by the intensity of the current from the selenium cell.

Sunbury. ALICE EVERETT.

New Developments in Resistance Amplification.

To the Editor, E.W. & W.E.

SIR,—In reply to the letter from Mr. E. B. Moullin, published in the August issue of *E.W. & W.E.*,—I certainly do not plead guilty to any misinterpretation or misconception. The product

$$\left(\frac{R_1}{R_1 + R_a}\right)\left(\frac{R}{R + R_a}\right)$$

is perfectly symmetrical as far as R and R_1 are concerned and there is no more reason for saying that R_1 must be large compared with R than there is for saying the exact opposite. In order that the product shall be nearly unity it is equally important that R shall be large compared with R_a and that R_1 shall be large compared with R_a, and that's all there is about it. However, I am prepared to admit that the form in which I stated this conclusion in my article was calculated to arouse comment.

Mr. Moullin's further contention that the use of moderate anode resistances will result in equally high amplification per stage will not stand the test of practice unless he is prepared to use very inconveniently high anode voltages, *i.e.*, voltages up to 500 or so.

In my opinion the more serious criticism of the use of very high anode resistances relates to frequency distortion. The high input capacity of a valve with a high anode resistance, more particularly in the case of a valve with a high voltage factor, is the real limiting factor in the case of multi-valve arrangements. This matter is being investigated and it is hoped that more detailed information will shortly be available, but as far as my experience is concerned very satisfactory reproduction is obtained by the use of high anode resistances with ordinary high-frequency valves.

F. M. COLEBROOK.

The Audio-Transformer Problem.

To the Editor, E.W. & W.E.

SIR,—I. observe that in your issue for August, Mr. E. Fowler Clark comments with some disfavour on my letter published in the June issue.

I feel this is unkind of him, for, on close reading of my letter, in conjunction with his own in the July issue, I think it appears that we are really in agreement on the principles of design.

We both emphasise that the valve A.C. resistance should equal the impedance of the transformer primary (neglecting any reaction of the secondary on it) at the lowest frequency to be effectively amplified.

Now I am mostly concerned with designing amplifiers giving really effective amplification down to 20 or 30 cycles when possible, and down to not less than 50 cycles anyway. I usually find that I want 80 to 100 henries of primary, and I find that to get it is not at all easy; in fact, it *is* the case, for me, that " L_1 will be as large as we can make it." This is, of course, subject to other limitations of design, such as self-capacity, D.C. ampere-turns, reasonable cost, and so on, some of them mentioned by him.

I find that with proper design the transformer (in spite of the statements of the resistance-coupling enthusiasts) has a very definite place, even in amplifiers with an effective frequency range of 20-8,000 cycles, and perhaps I was thinking too much of this kind of apparatus, and forgot that if one is content with a lower limit of 100 or 200 cycles, the best primary need not be " as large as we can make it."

But my statement still seems true to me for really first-class work.

I do not think it necessary for me to discuss in detail Mr. Fowler Clark's other comments on my letter, as the main principle is the important thing.

New Eltham. P. K. TURNER.

Some Recent Patents.

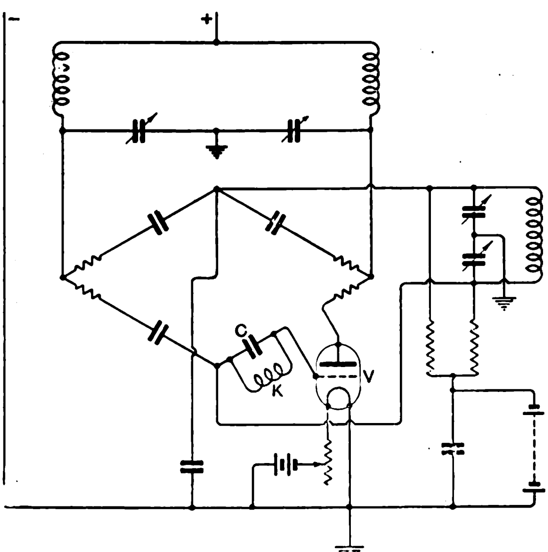
The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

HIGH FREQUENCY BALANCERS.

(*Application date, 11th February*, 1926. *No.* 270,800.)

In a Wheatstone bridge system, such as that shown in the figure, for decoupling or disassociating the plate and grid circuits of an amplifier *V*, Mr. E. Green points out that the accuracy of balance, at frequencies of the order of ten thousand kilocycles per second, is liable to be upset owing to the inductive reactance of the external valve leads or connections.

In order to compensate for this effect, a vectorially negative reactance, such as the condenser *C*, is inserted in the grid lead of the valve *V* for the specific purpose of neutralising the positive inductive reactance, at the given working frequency, of the length of wire between the lower bridge junction and the grid terminal. A shunt choke-coil *K* allows the passage of direct grid current. Apart

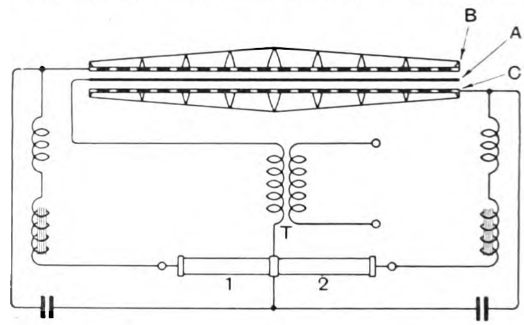


from this refinement, the general arrangement of the balanced bridge is identical with that described in a former patent No. 241,289 issued jointly to Mr. C. S. Franklin and the present inventor.

AN ELECTROSTATIC LOUD-SPEAKER.

(*Application dates, 23rd and 30th December*, 1925. *No.* 271,125.)

A movable diaphragm *A* is mounted for free vibration between fixed upper and lower electrodes *B*, *C*. A normally high potential difference is maintained between the fixed and movable members, but is so balanced that no effective force is applied to the movable diaphragm before the application of voice signalling currents. The fixed electrodes *B*, *C* may be in the form of metal-gauze



screens suitably supported, and are connected to the opposite poles of two dry piles 1, 2. The latter may be of the Zamboni type, formed of a number of adjacent paper discs coated on one side with black oxide of manganese and on the other with tin or silver foil.

The movable diaphragm is a rigid structure, exceedingly light in character, and so mounted that whilst it is free to vibrate to and fro, it cannot be twisted or distorted as a whole with reference to the plane containing its outer periphery. It is connected through the secondary winding of a transformer *T* to the common junction of the two piles 1, 2. Speech frequency currents for reproduction are applied across the primary of the transformer *T*, and by upsetting the existing electrostatic balance throw the centre diaphragm *A* into vibration. The diaphragm and electrodes may be made conical instead of flat, and as many as five may be employed: namely, a fixed central plate, two parallel outer movable diaphragms, and an outside pair of fixed gauze electrodes similar to *B*, *C*. The patent is issued to M. and A. Graham and W. J. Rickets.

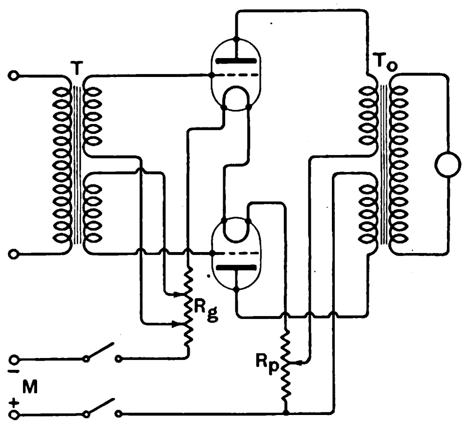
PUSH-PULL AMPLIFIERS.

(*Application dates, 14th and 30th April*, 1926. *No.* 271,222.)

In order to preserve strict symmetry between the plate, grid, and filament voltages of amplifying valves arranged in push-pull relation, special precautions must be taken where the filaments are supplied in series instead of in parallel. Series feed is advantageous when, for instance, the supply is taken from the domestic mains.

The British Thomson Houston Co. describe a method of feeding push-pull amplifiers from the mains, whilst at the same time preserving a strict

symmetry between the operating potentials. The secondary winding of the input transformer T is divided, and tappings are taken to separate points on the grid bias resistance R_g. Similarly the primary of the output transformer T_0 is split, the



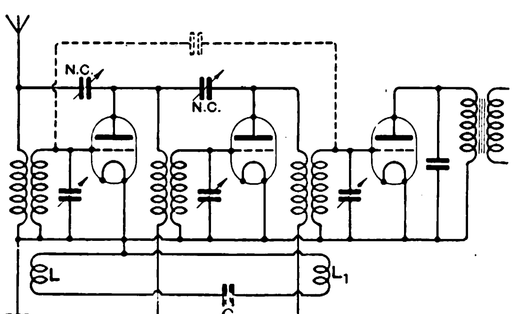
two tappings being taken to selected points on the resistance R_p, forming the source of the plate voltage. It will be seen that both resistances R_g and R_p, together with the two valve filaments, are all in series across the terminals of the supply mains M.

NEUTRALISING H.F. AMPLIFIERS.

(*Application date*, 8*th June*, 1926. *No.* 271,253.)

Magnetic coupling through a closed circuit L, L_1, C is utilised by the Igranic Co. and Mr. P. W. Willans, to compensate for the residual inherent capacity reaction that exists between H.F. amplifiers —even when "stabilised" by the ordinary neutralising condensers as shown at NC.

The coil L preferably consists of only two turns of stiff wire, and is coupled to the grid of the first valve. A similar coil L_1 is coupled to the third or



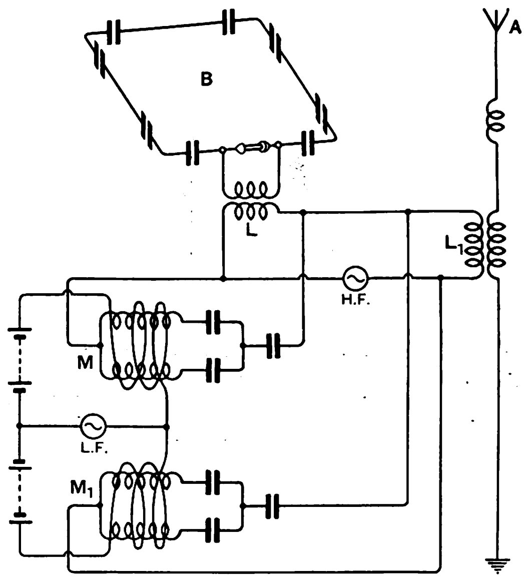
any other subsequent valve, so that at least two stages of valve amplification separates the two coils. The condenser C has a capacity of 0.006μF. As shown the closed coupling-circuit is connected to the filament system.

PREVENTING FADING.

(*Convention date* (*U.S.A.*), 30*th November*, 1925. *No.* 262,152.)

In this patent issued to the British Thomson Houston Company, Limited, as assignees of E. F. W. Alexanderson, an attempt is made to overcome faulty reception due to fading. It is pointed out that the incidence of the distant fading effect is a function of the polarisation of the emitted wave. If the polarisation is kept constant, a receiver in any given location may therefore be subjected to considerable intervals of total fading. On the other hand, by continuously varying the plane of polarisation, the area of bad reception is constantly being shifted, so that any given receiver will pick up sufficient energy to give a continuous average response of reasonable strength.

As shown in the figure radiation takes place alternately from a vertical aerial A which emits a



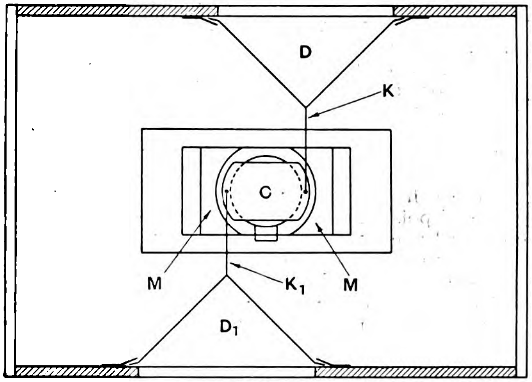
vertically polarised wave, and from a loop aerial B which produces a horizontally polarised wave. High frequency oscillations from the source HF are transferred alternately through a magnetic modulator M_1 and coupling L_1 to the aerial A, and through a second modulator M and coupling L to the loop B, the frequency of the change-over being controlled by a low frequency alternator LF.

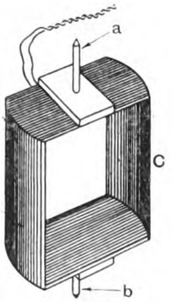
LOUD-SPEAKERS.

(*Application date*, 9*th February*, 1926. *No.* 271,021.)

Dr. N. W. McLachlan's object is to produce a loud-speaker, or microphone, in which inherent resonance is reduced to a minimum, and is localised below the important audio frequency range, and from which objectional directional characteristics are absent. The coil C (shown separately) is freely mounted on axes a, b set between the poles

of the magnet M. It is connected by means of members K, K_1 with two diaphragms D, D_1, which may be of conical or other form. The peripheries





of the diaphragms are loosely held between V-shaped strips of flexible material.

The restoring force is consequently very small, being provided by the peripheral mounting of the diaphragms. Instead of using only two diaphragms, any desired number may in fact be linked up with the vibrating coil, and may be of equal or different sizes. This arrangement ensures a more uniform distribution of sound than can be secured from a single diaphragm, owing to the focusing propensities of the latter at high frequencies.

A CONSTANT COUPLING ARRANGEMENT.

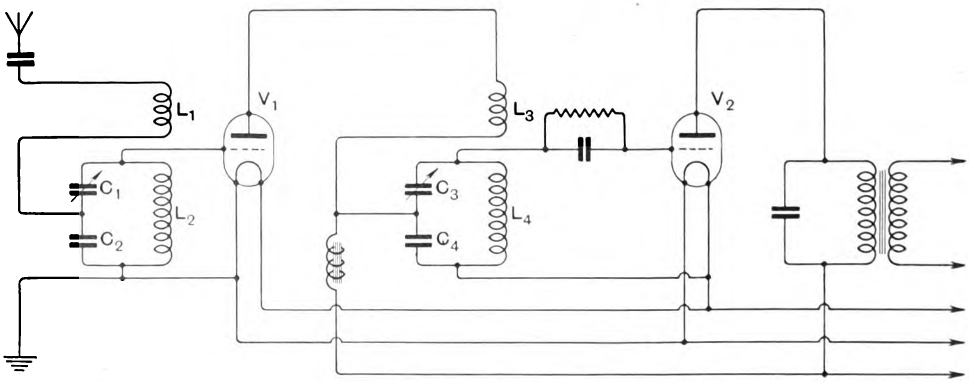
(*Convention date* (*U.S.A.*), *11th August*, 1925. *No.* 256,967.)

The names of Messrs. Loftin and White are already familiar to most experimenters in connection with the subject of constant coupling. In this British patent Mr. Sidney Young White covers a particular circuit arrangement designed for the purpose of (*a*) ensuring a constant rate of energy-transfer between two coupled valve amplifiers over a wide range of frequencies, and (*b*) preventing self-oscillation due to capacity reaction across the valve electrodes.

Taking the intervalve coupling first, it will be seen from the figure that energy will be transferred from valve V_1 to valve V_2 partly by the magnetic coupling between the coils L_3 and L_4, and partly by capacity coupling across the condenser C_4, which is common to the output of the first and the input of the second amplifier. The input circuit of the valve V_2 is tuned as a whole by the variable condenser C_3.

The energy transfer through the condenser C_4 will decrease as the received signals increase in frequency, whilst the transfer across the coils L_3, L_4 will increase under the same circumstances. If the direction of the coil L_3 is such that the induced magnetic and electric energy components are both in phase, the observed variations with frequency will mutually counterbalance, so as to ensure a constant over-all coupling throughout the entire tuning range.

A similar arrangement is used for coupling the aerial circuit to the input of the first amplifier, and the same considerations apply. By suitably adjusting the relative values of the coupling condenser C_2 and the tuning condenser C_1, the energy transfer from the aerial may be arranged either to increase or decrease with frequency variation, instead of remaining constant.



Reaction across the internal valve electrodes is reduced to negligible dimensions by limiting the value of the inductance L_3 and capacity C_4 to such dimensions that the plate circuit of the amplifier V_1 can never approach resonance with its input circuit.

EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. OCTOBER, 1927. No. 49.

Editorials.

Screened Valves.

THE use of screened valves for radio-frequency amplification is now claiming the attention of many of the advanced workers in the radio field. In our present issue two articles deal in a fundamental manner with the problem and several papers on the subject have been published in recent issues of the *Wireless World*. No one can read these without being impressed with the possibilities of further development in the design and use of thermionic valves. Finality appears as far off as ever; a few months ago the three-electrode valve with a carefully designed neutrodyne circuit seemed to be as near to the ideal as one could hope to attain, although all those who worked at the problem knew that the solution was not all that could be desired. Now we foresee thousands of enthusiasts during the coming winter taking down their neutralised high-frequency stages and exploring the possibilities of screened valves.

One must not imagine, however, that the screened valve is an entirely new invention. Valves with two grids have been used for many years, especially in Germany where their properties were investigated both theoretically and experimentally by W. Schottky in the Siemens laboratories. Such double-grid valves were used in two entirely different ways. The first was due to Langmuir of the General Electric Co. of America, who in 1913 inserted a second grid between the filament and the usual control grid. This second grid was given such a positive potential with respect to the filament that the electron emission was near saturation. The positive potential of this grid may be regarded as counteracting the negative potential of the space charge, and it is commonly known as the space-charge grid or screen. The effect is to make the i_a-v_g characteristic steeper, *i.e.*, to increase the mutual conductance, at the same time decreasing the internal resistance. It is claimed by Wirtz in the *Taschenbuch der Drahtlosen Telegraphie* that the amplification is three times that obtained with the three-electrode valve.

The second method of using an additional grid was introduced by W. Schottky of Messrs. Siemens and Halske in 1916 and it is this invention of Schottky which forms the basis of the screened valve. The additional grid was introduced between the ordinary control grid and the anode and was connected to a point on the H.T. battery so that its potential was somewhat less than that of the anode which it screened. Schottky called it the anode-screen grid because the additional grid screened the control grid from the alternating potential of the anode. Such valves had a very high internal resistance and a steep characteristic; they could be worked with a lower anode voltage than the three-electrode valve.

These valves are known in Germany as SS valves (Siemens-Schottky).

Although little use has been made of these

valves in this country, they have been used to some extent in Germany. Von Ardenne's book on the construction of resistance-coupled amplifiers has a chapter on screened valves and their application to amplifiers, but the conclusions to which he comes are not at all in accord with the views underlying the latest developments.

Although Schottky pointed out in January, 1921, that by suitable design of the leads in the bulb and also of the socket the capacity between the grid and anode circuits can be so reduced that there is no danger of self-excitation due to back-coupling, interest in the subject has only recently been aroused by the work of Hull and Williams in America. These two workers have improved the screening by making the screening grid enclose the anode as much as possible, thus making it impossible for any electron to reach the anode without running the gauntlet of the small meshes in the screen. In the language of Schottky they have decreased the "Durchgriff" between the control grid and the anode. They have thus carried the ideas of Schottky as far as possible with results which open up new possibilities in radio-frequency amplification, as will be seen by a perusal of the articles on the subject in this issue.

National Wireless Exhibition, Olympia, 1927.

At the time this issue appears the annual wireless show at Olympia will be in progress, and this provides a unique opportunity for getting a general impression of the development of practical wireless apparatus, though, of course, the bulk of the exhibits are confined to the more popular side of broadcasting. Engaged on work of some specialised character it is often difficult to keep in touch with what is being done in the wider practical applications of the science, so that a visit to the Exhibition is well worth while as an opportunity for bringing our knowledge up to date in this respect.

Wireless as applied to broadcasting has been passing through a period of evolution during the past few years, and to-day it is, in the main, becoming more stabilised, although the appearance of new apparatus such as the screened valves, to which we referred above, remind us that we cannot stand still and consider any phase of development as approaching finality. In addition to the screened valves, the attention of the manufacturers of broadcast apparatus appears to have been devoted mainly to the simplification of broadcast receivers and improvement of quality of reproduction. There was a time when even the broadcast receiver which was developed for the use of the layman was a veritable mass of knobs and controls, but to-day a process of weeding out of unnecessary or auxiliary tuning devices has cleaned up the appearance of the panel of the set to a surprising extent. To take only one example, the temperature at which filaments of valves should operate is no longer as critical as formerly, and it has been possible, as a result, to dispense with individual filament rheostats for the valves, and, in many modern receivers, fixed or semi-fixed resistors, not visible on the panel, replace the row of knobs which was characteristic of the early sets.

In attending to quality, it is interesting to note that the development of suitable valves has served as an impetus to manufacturers to put out resistance coupling units in the endeavour to improve quality of reception.

Loud-speakers have also received considerable attention, and this is illustrated by the growing popularity of the free coil drive type and the numerous types of cone loud-speakers which are fast proving their superiority over the ordinary horn type of instrument.

It has been recognised for some time that one of the essentials of good quality is adequate H.T. supply for the anodes of the valves, and we have as a result a large variety of units designed for supplying current from the mains for the receiver; and valves which have their filaments heated from the mains direct. The competition with manufacturers of H.T. eliminators has also given an impetus to the manufacturers of batteries, both primary and secondary, and surprising improvements have been brought about in these products.

We hope in our next issue to deal individually with some of the outstanding exhibits of the Show.

Calculation of the Polar Curves of Extended Aerial Systems.*

By E. Green, M.Sc.

AERIAL systems consisting of a large number of wires in the same plane properly associated and excited so that the currents are always in the same phase, have very marked directional properties, provided the dimensions of the system are large compared with the wavelength. These aerial systems were originated and developed practically, together with the necessary feeding system, by Mr. C. S. Franklin, of the Marconi Company, during the years 1922 and 1923. Mr. Franklin worked out the complete theory, and calculated the directional effect and energy magnification possible, and verified the results experimentally. I was asked by Mr. Franklin to check his calculations, and during this work developed the methods of calculation and ways of thinking of the working which are given in the following paper.

The case considered is that of a line of aerials, the adjacent ones separated by a small fraction of a wavelength, and the whole system extending in a straight line several wavelengths long. Such a system is represented in Fig. 1, each vertical aerial (shown as a dot) has an equal current in it, and the phase is the same in all the aerials. This will be the case if each aerial or group of adjacent aerials is fed from a common transmitter by cables of equal electrical lengths. At a distant point P the current in each aerial, if it acted alone, would produce a certain alternating strength of electric field, which can be represented by an elementary vector. When all the aerials are present (each with an equal current) the vector representing the resultant field strength at P is obtained by summing up these elementary vectors. For distant points in the direction OA at right angles to the system, the field due to each aerial will be in phase and the elementary vectors are in a straight line as shown in Fig. 1(a). The resultant is therefore OR. For a distant point P in any direction θ the elementary vectors of field intensity are not in phase. Thus, starting from the end B,

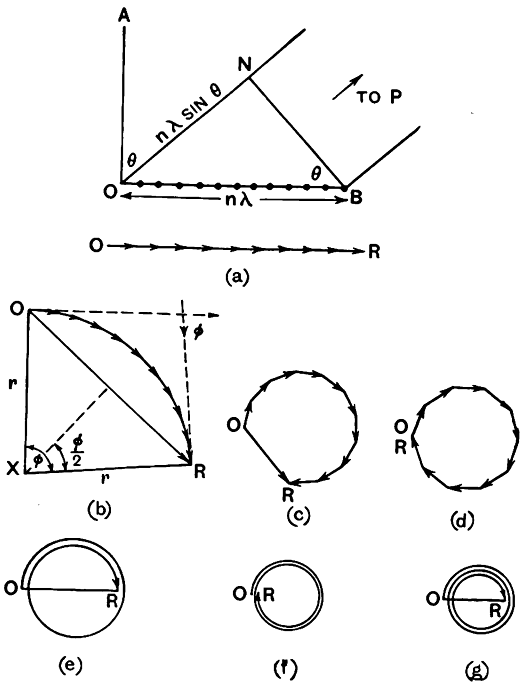


Fig. 1.

with the direction of P as shown, the elementary vectors due to consecutive aerials will lag in phase by a constant amount. Hence they take the form of Fig. 1(b). Since the elementary vectors are of equal length and change in direction by equal amounts, they form practically an arc of a circle, and we shall treat them as such. The resultant field strength is therefore represented by the straight line OR. (Fig. 1(b)).

* [We would draw the attention of readers interested in this subject to a paper by Ronald M. Foster entitled "Directive Diagrams of Antenna Arrays," published in the April number (Vol. V., No. 2) of the *Bell System Technical Journal*. This article gives many references to previous work on the subject.—ED.]

To find the value of OR for any angle θ we proceed as follows: Note first that the length measured along the arc OR is a constant and equal to OR in Fig. 1(a) $= E$, say.

Second, the angle $OXR (= \phi)$, subtended by the arc at the centre of the circle, is by the geometry of the circle equal to the angle of phase difference between the first and last vectors. Now from Fig. 1 the lag of the vector due to O behind that due to B is

$$ON = n\lambda \sin \theta$$

in distance where $n\lambda$ is the length OB of the aerial system.

If lag in distance is λ the lag in phase is 2π radians (or 360°). Hence

$$\phi = \frac{2\pi n \lambda \sin \phi}{\lambda} = 2\pi n \sin \theta \quad \ldots \quad (1)$$

If r equals radius of circle, we have

Length of arc $OR = r\phi$ (radians)

Length of st. line $OR = 2r \sin (\phi/2)$

Therefore

$$\frac{\text{Field intensity in direction } \theta}{\text{Field intensity in direction } OA} = \frac{\text{st.line } OR}{\text{arc } OR}$$

$$= \frac{2r \sin \frac{\phi}{2}}{r\phi \text{ (rad.)}} = \frac{\sin \frac{\phi}{2}}{\phi/2} \quad \ldots \quad (2)$$

$$\text{Resultant} \quad OR = \frac{E \sin \frac{\phi}{2}}{\phi/2}$$

If we calculate the value of this expression for various values of θ we shall be able to plot the polar curve of the system. This has been done in Fig. 2 for a system 2λ long. But we can get a good general idea from a direct consideration of the forms assumed by the vector diagrams. As the angle θ increases from 0° the angle ϕ steadily increases. The vector diagram first takes the form of Fig. 1(b), then that of Fig. 1(c), then that of Fig. 1(d). In this last the resultant is zero. Clearly this occurs when the first and last vectors differ by 2π in phase, *i.e.*, when

$$2\pi n \sin \theta = 2\pi$$

or

$$\sin \theta = 1/n \quad \ldots \quad \ldots \quad (3)$$

For a system two wavelengths wide ($n = 2$) this gives $\sin \theta = \frac{1}{2}$ and $\theta = 30°$. Up to this point the resultant field intensity has therefore steadily decreased from its value at $\theta = 0°$. For further increase of θ the elementary vectors begin to overlap and the resultant OR increases to a maximum approximately when OR becomes the diameter of the circle. (Fig. 1(e)). This occurs when the first and last vectors have 3π difference in phase,

i.e., $\quad 2\pi n \sin \theta = 3\pi, \ \sin \theta = 3/2n.$

For a system 2λ wide ($n = 2$) this gives

$$\sin \theta = \tfrac{3}{4}, \quad \therefore \ = 49.5°.$$

The relative magnitude of this first side maximum is independent of the width of the system. We have

$$\frac{\text{Intensity at this angle } \theta}{\text{Intensity at } 0°} = \frac{OR}{1\frac{1}{2} \text{ circumference}} = \frac{d}{\frac{3}{2}\pi d}$$

$$\text{Resultant} \quad OR = \frac{2}{3\pi} E = \underline{.212E}.$$

The next stage of the vector diagram is that of Fig. 1(f), where the resultant intensity is zero again, when $\phi = 4\pi = 2\pi n \sin \theta$. For $n = 2$ this gives $\sin \theta = 1$, $\theta = 90°$.

In this particular case this completes the curve, since each quadrant is the same. One-half of the exact curve is shown in Fig. 2. The back half is exactly the same.

For wider aerial systems the next form is shown in Fig. 1(g). Here

$$2\pi n \sin \theta = 5\pi, \ \therefore \ \sin \theta = \frac{5}{2n}$$

and

$$OR = \frac{2}{5\pi} . E = .127E$$

We can now see the general rule. This is given in the table below.

$\sin \theta =$	0	$\frac{2}{2n}$	$\frac{3}{2n}$	$\frac{4}{2n}$	$\frac{5}{2n}$	$\frac{6}{2n}$	$\frac{7}{2n}$	$\frac{8}{2n}$	$\frac{9}{2n}$
Intensity of field ...	1	0	$\frac{2}{3\pi}$	0	$\frac{2}{5\pi}$	0	$\frac{2}{7\pi}$	0	$\frac{2}{9\pi}$
If $n = 10, \theta =$	0	$5\frac{3}{4}°$	$8\frac{5}{8}°$	$11\frac{1}{2}°$	$14\frac{1}{2}°$	$17\frac{1}{2}°$	$20\frac{1}{2}°$	$23\frac{1}{2}°$	$26\frac{3}{4}°$ etc.

The series ends when $\sin \theta = 1$, *i.e.*, $\theta = 90°$. For example, if width of system is

10 wavelengths the values of θ are given in the last line of the table. There will be side loops corresponding to all odd numbers between 3 and 19 inclusive, *i.e.*, 9 in all. A drawing of half the polar curve is given in Fig. 3.

[The position of the minima is given accurately in the above table, but the position and value of the side maxima are

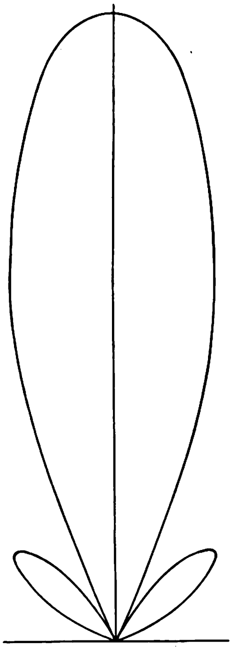


Fig. 2. *Polar curve of system 2λ wide.*

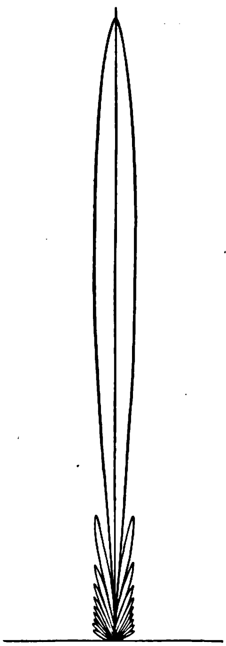


Fig. 3. *Polar curve of system 10λ wide.*

only approximate, more especially as regards the first. The accurate positions of the side maxima are given by

$$\frac{d}{d\frac{\phi}{2}}\left(\frac{\sin\frac{\phi}{2}}{\phi/2}\right) = 0$$

or

$$\frac{\cos\frac{\phi}{2}}{\phi/2} - \frac{\sin\frac{\phi}{2}}{(\phi/2)^2} = 0$$

that is

$$\tan\frac{\phi}{2} = \frac{\phi}{2}$$

This gives values for $\phi/2$ of 1.43π, 2.45π, 3.47π, etc., instead of 1.5π, 2.5π, 3.5π, given by the approximate calculation.

For the first side maximum we get the value $.217E$ instead of $.212E$, and for $n=2$ the angle of the first side maximum comes out at 46° instead of 49.5°. The approximate calculation is therefore good enough for most purposes.]

By placing another set of aerials at a quarter wavelength behind the first set, as shown in Fig. 4, we can reflect practically all the energy that would go in this direction. The shape of the polar curve in front is not appreciably affected, but the energy in it for a given input will be doubled.

[The accurate polar curve for the system with reflector can be obtained by multiplying the polar curve of the extended aerial alone, by the heart-shaped polar curve given by a system consisting of a single aerial, and a single reflector wire a quarter wavelength behind it. The reflector wire is assumed to carry a current equal to that in the aerial wire and leading it by 90°. The equation of the curve is

$$r = \cos\frac{\pi}{4}\,(1 - \cos\phi)$$

The values of r for various values are given in the table below :—

$\theta=0°$	30°	45°	60°	90°	135°	180°
$r=1$	.994	.974	.924	.707	.225	0

From these it will be seen that the statement that the reflector only slightly affects the polar curve in front is true.

The polar curve for the extended aerial and reflector will be

$$r = \frac{\sin\,(n\pi\,\sin\theta)}{n\pi\,\sin\theta}\,\cos\left\{\frac{\pi}{4}\,(1 - \cos\theta)\right\}\,]$$

It should be noticed that an extension of

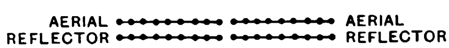


Fig. 4.

the aerial system in the vertical plane to one wavelength or more of height (providing the current is in the same phase throughout) will result in a concentration in the vertical plane. This can be effected by making each vertical aerial unit a number of independent half-wave aerials as shown in Fig. 9(c), and keeping the currents in all of them in the

same phase by the appropriate feeding system. The current distribution in the aerials is shown by the dotted lines. It is not uniform, but the polar curve of intensity in the vertical plane at right angles to the system can be calculated approximately in a manner similar to that used for the horizontal plane. It must be remembered, however, that even a small vertical aerial is directional in the vertical plane, its polar curve being as shown in Fig. 9(a), O being the pole. If the aerial system is $n\lambda$ in height, and we assume a good conducting earth (thus making it equivalent to a system $2n\lambda$ in height in free space) the intensity at an angle θ will be proportional to

$$\frac{\sin\,(2\pi n \sin\theta)}{2\pi n \sin\theta}\cdot\cos\theta.$$

The cosine factor is due to the fact that the intensity of field due to a vertical aerial is proportional to the cosine of the altitude, *i.e.*, proportional to $\cos\theta$.

Fig. 9(b) gives the approximate shape of the curve for a system one wavelength in height, near a good conducting earth, or for one, two wavelengths in height in free space.

Energy Magnification of an Extended System as compared with a Single Aerial.

The accurate way to calculate the energy magnification is as follows: Assume a certain intensity of field I is to be provided at the receiver, then in the case of the single aerial we can find the intensity of field at all points on the surface of the sphere (or hemisphere when dealing with a system near earth) which has its centre at the transmitter, and passes through the receiver. We can therefore sum up the total energy that passes through the surface of this sphere per second. This power must be provided at the transmitter. Let it be represented by A. In the same way we can calculate the power B required by the extended system to give the same intensity of field at the receiver. It follows directly that if the same power is provided for the single aerial and for the extended system the available power at the receiver for the extended system will be A/B times that for the single aerial. This fraction A/B may be called the energy magnification or power magnification of the extended system as compared with the single aerial. It will be seen that this calculation is a laborious process involving integration over the surface of a sphere, but we can arrive at an approximate value of the "energy magnification" of an extended system as compared with a single aerial *of the same height* and gain an insight into the methods of calculation by comparing the power radiated in the two cases through an equatorial zone MN of unit depth (Fig. 5(a)) instead of through the whole sphere. The ratio thus found would be approximately true, for the zones of the sphere through which most of the energy passes (*i.e.*, those lying near the equatorial plane), and would therefore give approximately the ratio of the total powers required in the two cases.

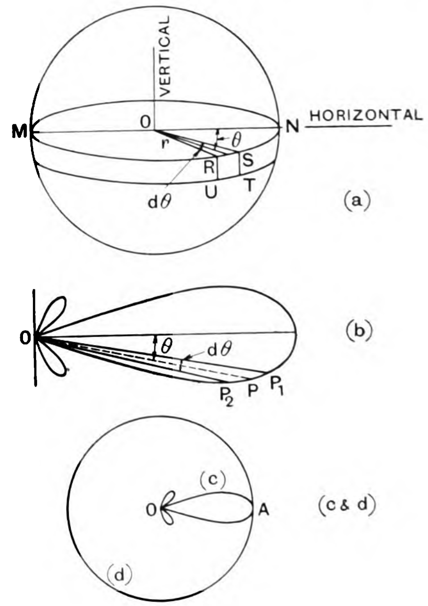


Fig. 5.

Energy Magnification due to an Extension in Width of the Aerial System.

Let the polar curve of intensity in the equatorial plane for the extended system be as shown in Fig. 5(b).

OP represents the intensity of the field in the direction θ at a distance r. The power radiated in this direction will be proportional to OP^2.

The area of the element $RSTU$ of the zone through which this intensity of energy

is radiated is $r.d\theta$ (since the depth of the zone was taken as unity). Hence the power radiated out through the zone within the angle $d\theta$ is proportional to $r.d\theta.OP^2$; and since r is constant, the energy is proportional to $OP^2.d\theta$. Now the area of the triangle OP_1P_2 of the polar curve of field intensity is $\frac{1}{2}OP^2d\theta$. Therefore the energy radiated through the angle $d\theta$ can be represented by the area of the polar figure contained within the angle $d\theta$. And by summation the total power radiated in all directions through the zone is represented by the total area enclosed within the polar curve of intensity of electric field.

Fig. 5(c) is the polar curve of intensity for a system two wavelengths wide with reflector. Let its area be c. A single vertical aerial radiates equally in all directions in the horizontal plane. Hence its polar curve of intensity is a circle, and to give the same intensity as the two-wavelength system it must have the radius OA. Let the area of this circle be d.

Hence, to give equal intensity at A we have :—

$$\frac{\text{Energy for } 2\lambda \text{ system}}{\text{Energy for single aerial}} = c/d$$

Or conversely for equal power input to the aerial system :—

$$\frac{\text{Power at receiver for } 2\lambda \text{ system}}{\text{Power at receiver for single aerial}} = d/c$$

i.e., energy magnification, $m = d/c$

This works out as 12.6 for a system two wavelengths wide with reflector. Other cases can be worked out in a similar fashion, and it will be found that if the width of the system is doubled the energy magnification is approximately doubled, and so on. That this will be so can be seen from two different points of view. Firstly, let us consider the effect of doubling the width of the system on the area of the polar curve. The greater part of the area is contained in the main loop, and we shall confine our attention to this. (For width 2λ, about 6 per cent. is in the side loops.)

The length of the line OP (Fig. 5(b)) is given by :—

$$\frac{\sin\frac{\phi}{2}}{\phi/2} = \frac{\sin(\pi n \sin\theta)}{\pi n \sin\theta}$$

where n is the width of the system in wavelengths; and for small values of θ, such as are represented in the main loop, we can replace $\sin\theta$ by θ without serious error.

Hence

$$OP = \frac{\sin(\pi n\theta)}{\pi n\theta}$$

Now double the value of n and halve the value of θ and the value of OP is unaltered. The small angle $d\theta$ must also be halved, and so therefore must the area of the triangle OP_1P_2. Hence the area of the main loop is halved (for the same maximum value) and the energy magnification is approximately doubled.

Secondly, we can consider the more direct physical effect of doubling the width of the system. Take an extended system consisting of aerial and reflector that requires a total input W to give an intensity of field I at the receiver, and therefore available energy at the receiver proportional to I^2. Two such

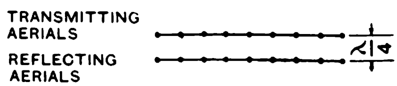


Fig. 6.

systems placed side by side as in Fig. 6 have little direct action on each other so that an energy input W to each will give the same currents as before. Hence if each system has energy input W they simply add their field intensities and the resultant field intensity now becomes $2I$, therefore for an input energy $2W$ we have an available energy at the receiver proportional to $(2I)^2=4I^2$. Hence with total energy W to the system of double extent, the energy at the receiver is proportional to $2I^2$; *i.e.*, its value is doubled when the width of the system is doubled, and so on.

Thus for a system ten wavelengths wide with reflector the energy magnification will be about 63. We can take an average figure of 6.3 for each wavelength of width. For the extended system without reflector the energy magnification per wavelength of width will be about 3.2. The reflector multiplies this figure by 2.

The polar curve for reception of such an extended system will be an exact replica of that for transmission. This can be seen by

working it out in detail, though it follows directly from fundamental principles. The energy magnification as compared with a single aerial of the same height will therefore be the same as that given above. The total magnification for the system using equal extended systems at transmitter and receiver as compared with single aerials at both ends will be m^2. For systems two wavelengths in width this is 160, while for those ten wavelengths in width it is $63^2 = 4{,}000$.

If the atmospherics at the receiving end come more or less equally distributed from all directions this full magnification will be obtained. If they come chiefly from outside the receptive angle of the system, the gain will be greater, while if they come inside this angle the gain will be less.

The accurate calculation by the method indicated of the energy magnification for aerial systems several wavelengths long and one or more wavelengths in height gives the following results: As compared with a small single aerial, the extended system with reflector gives an energy magnification of 10 for each square wavelength of surface. If the height of the system is m, and its width n, the energy magnification will be $10mn$. Thus if the system is ten wavelengths long and two wavelengths high, the energy magnification will be $10 \times 20 = 200$. Two such systems, one as receiver and one as transmitter, will therefore have an effective energy magnification of $200^2 = 40{,}000$.

That is to say, with two such aerials, one as transmitter and one as receiver, and one kilowatt input to the transmitter, we get a certain strength of signal at the receiver. Then working over the same distance with single aerials at both transmitter and receiver we should have to supply 40,000 kilowatts to the transmitter to obtain the same strength of signal at the receiver.

If we consider an aerial system of fixed extent in the horizontal plane, we see that the energy magnification per wavelength of extension in height as compared with a system of negligible height will be $10/6.3 = 1.6$. This is smaller than the figure (*i.e.*, 3.2) per wavelength extension in the horizontal plane, for two reasons:—

1. Even a small vertical aerial has considerable directional properties in the vertical plane, the intensity being proportional to the cosine of the altitude. (See Fig. 9(a).)

2. The area of the zones through which the energy is radiated also decreases as the cosine of the altitude.

Other Aerial Systems.

The same method of calculating the polar curves can be applied to other extended systems. Thus we may have a line of aerials like those shown in Fig. 7, but fed so that their effects added up in phase in the direction OB. This would require that starting from O the phase of the currents in

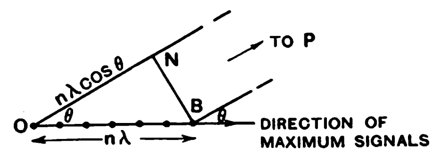


Fig. 7.

consecutive aerials would lag by a constant amount. In particular the phase of the current in B would have to lag

$$n\lambda \times \frac{2\pi}{\lambda} = 2\pi n \text{ radians } (= n.360^\circ)$$

behind that in O.

To find the polar curve in this case we shall measure the angle θ from the direction OB, the direction of maximum intensity. A similar line of argument to that used in the previous case will show that the vector diagram starts as a straight line for $\theta = 0^\circ$ and bends into a circular form as θ is increased. We have only to determine the angle of lag ϕ between the vector field intensities produced by the extreme elements at a distant point P for any angle θ. This angle ϕ will be the angle subtended by the circular arc of the vector diagram, and as before the resultant intensity of field for that direction as compared with that in the direction OB will be

$$\frac{\sin\frac{\phi}{2}}{\phi/2}$$

We have then (*a*) the current in B lags $2\pi n$ radians behind that in O; (*b*) For the direction θ the effects from O have to travel a distance ON greater than the effects from B. $ON = n\lambda \cos\theta$, and in phase angle it is

equal to

$$\frac{2\pi n\lambda \cos\theta}{\lambda} = 2\pi n \cos\theta \text{ radians.}$$

The resultant phase difference ϕ for the angle will be the difference between these two effects, and is therefore

$$2\pi n - 2\pi n \cos\theta = 2\pi n\,(1 - \cos\theta) = \phi.$$

With this definition of ϕ all the Figs. 1(b) to 1(g) apply to this case also. We shall have a minimum wherever $\phi = 2\pi,\ 4\pi$, etc., *i.e.*, when :—

$$n\,(1 - \cos\theta) = 1, 2, 3, \text{etc.}$$

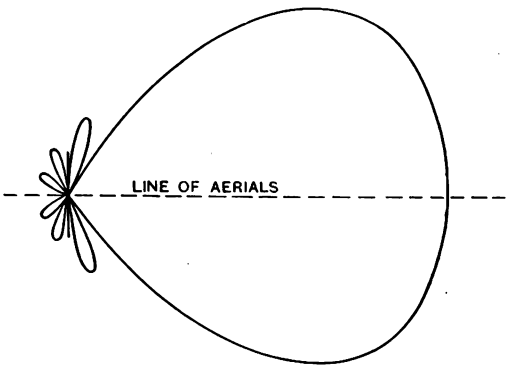


Fig. 8.

Minimum for

$$\cos\theta = \left(1 - \frac{1}{n}\right), \left(1 - \frac{2}{n}\right), \left(1 - \frac{3}{n}\right), \text{etc.}$$

There will be a maximum when

$$\phi = 0,\ 3\pi,\ 5\pi,\ 7\pi, \text{ etc.}$$

Maximum for

$$\cos\theta = 1, \left(1 - \frac{3}{2n}\right), \left(1 - \frac{5}{2n}\right), \text{etc.}$$

Values of maxima $1, \frac{2}{3\pi}, \frac{2}{5\pi}$, etc.

The limit of these series is fixed by the fact that $\cos\theta$ cannot have a greater negative value than -1, which it reaches when $\theta = 180°$. Hence the polar figure consists of one main maximum at $\theta = 0°$ and a series of side maxima steadily decreasing in value as θ increases from 0° to 180° on either side of the line OB.

The polar curve for the case $OB = 2\lambda$ is given in Fig. 8. It is a unidirectional figure, unlike that for the single line of aerials previously treated which by itself was bi-directional. For $OB = 2\lambda$ $(n = 2)$ we shall

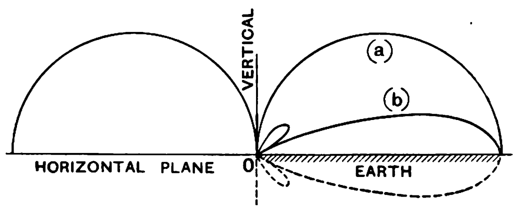


Fig. 9a. Fig. 9b.

have minima and maxima as given in the table.

TABLE OF MAXIMA AND MINIMA FOR $OB = 2\lambda$.

$\cos\theta =$	1	$\left(1-\frac{1}{n}\right)$	$\left(1-\frac{3}{2n}\right)$	$\left(1-\frac{2}{n}\right)$	$\left(1-\frac{5}{2n}\right)$	$\left(1-\frac{3}{n}\right)$	$\left(1-\frac{7}{2n}\right)$	$\left(1-\frac{4}{n}\right)$
$\cos\theta =$	1	$\frac{1}{2}$	$\frac{1}{4}$	0	$-\frac{1}{4}$	$-\frac{1}{2}$	$-\frac{3}{4}$	-1
$\theta =$	0°	60°	75.5°	90°	104.5°	120°	138.5°	180°
Intensity of field =	1	0	$\frac{2}{3\pi}$	0	$\frac{2}{5\pi}$	0	$\frac{2}{7\pi}$	0

It will be noticed that the first minimum comes 60° on either side of the main maximum instead of 30° on either side for the two-wavelength front, with reflector previously treated.

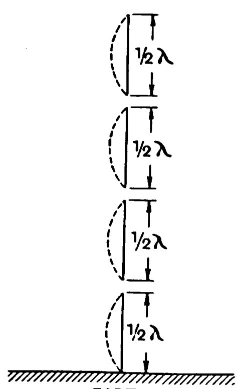


Fig. 9c.

Other points to be noticed with this system are :—

First, that it gives a concentration of energy in the vertical plane as well as in the

horizontal plane even when the vertical height of the aerials is small, the energy being concentrated into a cone with the line of aerials as its axis.

Secondly, notice that to halve the angle at which the first minimum occurs, we have to increase the length of the system approximately four times and so on. For we saw that the value of θ for the first minimum was given by

$$\cos\theta = 1 - \frac{1}{n}$$

and when θ is small we can replace it by $1 - \frac{\theta^2}{2}$, which gives us $\frac{\theta^2}{2} = \frac{1}{n}$ thus proving the statement.

To find n to give $\theta = 30°$ we have

$$\cos 30° = .866 = 1 - \frac{1}{n}$$

$$n = \frac{1}{.134} = 7.46$$

The aerial system using a reflector only requires to be two wavelengths wide to give the first minimum at 30°.

Some Measurements of a "Stalloy" Core with Simultaneous D.C. and A.C. Excitation.

By L. B. Turner, M.A., M.I.E.E.

SMALL chokes and transformers are widely used in association with triodes in such a way that the core has to carry simultaneously a steady and an alternating magnetic flux. The presence of the steady component of current in the winding may profoundly influence the behaviour of the choke as regards the alternating P.D. In many wireless telephone receivers such a choke is employed—

(*a*) in the smoothing mesh of a rectifier supplying high-tension D.C. from A.C. mains ;

(*b*) in association with a condenser preventing anode current from passing through the loud-speaker ; and

(*c*) as an iron-cored choke or transformer in one or more stages of the low frequency amplifier.

In each case the winding has to pass a steady direct current and at the same time to offer the greatest possible impedance to alternating P.Ds. applied to it. In case (*a*), the alternating P.D. is constant in magnitude and frequency, and it is not essential to good performance that the impedance shall be indefinitely great. But in cases (*b*) and (*c*), the alternating P.D. fluctuates over wide ranges of amplitude and over the whole range of acoustic frequencies, and it is essential for good performance that at all

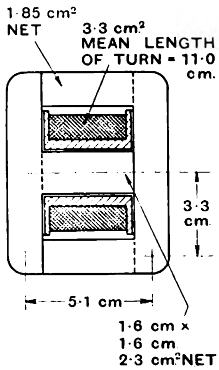


Fig. 1.

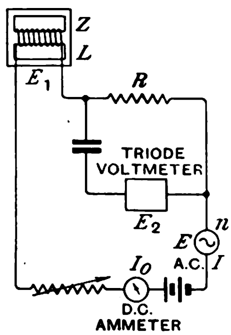


Fig. 2.

amplitudes and frequencies the impedance shall be indefinitely great compared with the anode A.C. resistance of the triode. It is common knowledge that, especially in case

(*c*), the design of the choke actually employed is very often such that it does not meet the condition for good performance.

The writer has had occasion to measure the behaviour of the choke shown in Fig. 1. As this choke is of a size and type much employed in the ways named above, and in others, the measurements were extended to cover a wide range of values, and are here presented in a form conveniently applicable to designers' calculations.*

The measurements were made as shown in Fig. 2, and the resu'ts are p!otted in Fig. 3. The applied alternating E.M.F. E being substantially sinoidal, it follows that the alternating current I is not sinoidal; but for our purposes we may, as is usual, call $Z=E_1/I$ the "impedance" of the choke (sensibly equal to its "reactance"), and $L=Z/2\pi n$ its "inductance," where E and I are the R.M.S. values of the alternating quantities. E_2, and sometimes E_1, were measured with a suitable triode voltmeter.

I is found as E_2/R,

and L as $(1/2\pi n) . R . (E_1/E_2)$.

In most of the measurements R/Z was small enough to allow the approximation $E_1 \doteqdot E$.

The choke tested was wound with 2,500 turns of copper wire, S.W.G. 32 D.W.S., D.C. resistance about 80 ohms. The frequency n was 90 cycles/sec. Since the cross-section of steel within the bobbin is about 2.3 cm.², with this number of turns and at this frequency the maximum alternating flux density in C.G.S. units is about 44 E, where E is in volts.* The makers' curves for "Stalloy" show a maximum permeability at a flux

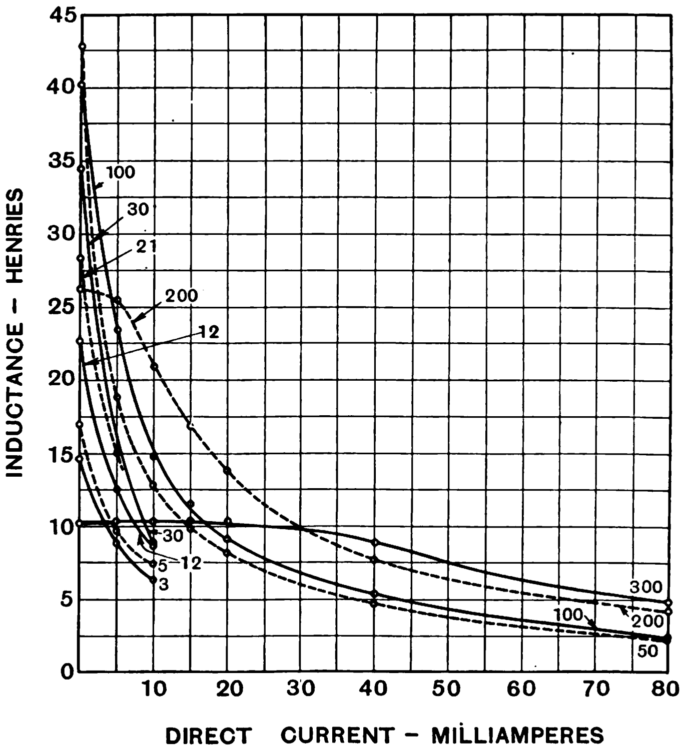


Fig. 3. *The numbers against the curves indicate in volts the R.M.S. value of the alternating P.D. across the choke at 90 cycles per second.*

* The core stampings and bobbin used in the actual choke tested are both readily obtainable. The former are Messrs. Sankey's standard transformer stampings Nos. 5, 14 and 15; and the latter is Messrs. Edison Bell's standard moulded transformer bobbin No. 150.

* In the rest of the core it is less, viz., about 28 E.

density of 4,000. Hence when $I_0=0$, we should expect the inductance to be a maximum when E has a value somewhat above $4{,}000/44=90V$. It will be seen in Fig. 2 that the measured inductance values were highest (about 40H) with 50V and 100V, and fell off progressively (towards about 10H) with the voltages lower than 50 and higher than 100.

In the Table, the results of Fig. 3 are put in a form convenient in calculating the performance, for any specified service, of various windings on this core; and the figures may be easily adapted to other fairly similar cores of the same material. As an illustration, let us use the Table to find the inductance of a 2,500-turns winding, with a direct current of 8mA and an applied alternating P.D. of 100V. at 90 cycles/sec. The D.C. excitation is $(8/1000)\times 2500=20$ ampere-turns. The A.C. voltage per 1,000 turns per 1,000 cycles/sec. is

$$100 \times (1{,}000/90) \times (1{,}000/2{,}500) = 445.$$

The Table therefore gives an inductance of about 2.9H for 1,000 turns, and therefore $2.9\times(2{,}500/1{,}000)^2=18.1H$ for 25,000 turns. This agrees with Fig. 3, which shows 17.9H for the specified values.

TABLE.

Inductance in henries of the specified "Stalloy" core if wound with 1,000 turns, when the D.C. excitation is 0, 5, - - - 160 ampere-turns, and the alternating P.D. per 1,000 turns and per 1,000 cycles/sec. is 13, 22 - - - 1,300 volts (R.M.S.).

A. C. volts (R. M. S.) per 1,000 turns and per 1,000 cycles/sec.*	D.C. excitation in ampere-turns.						
	0	5	10	20	40	80	160
13	2.3	1.9	1.5	1.1	—	—	—
22	2.7	2.1	1.7	1.3	—	—	—
53	3.6	2.7	2.2	1.6	—	—	—
90	4.5	3.4	2.7	—	—	—	—
130	5.5	4.0	3.0	1.8	—	—	—
220	6.8	4.4	3.4	2.3	1.5	0.9	0.5
440	6.4	5.2	4.2	2.9	1.7	1.0	0.5
900	4.2	4.2	4.1	3.7	2.6	1.5	0.8
1,300	1.7	1.7	1.7	1.7	1.6	1.6	1.0

* Maximum flux-density in central core is 10.8 times the number in this column.

Radio-Frequency Transformers.

Their Application to Screened Valves.

By N. W. McLachlan, D.Sc., M.I.E.E., F.Inst.P.

THE use of an intervalve radio-frequency transformer for wavelengths within the band 300 to 600 metres has always seemed to possess possibilities which have only been realised in practical form recently. Some three or more years ago, efforts to construct radio-frequency transformers usually met with little success. This was due to improper design which was associated with two undesirable features, namely, (1) high resistance secondary winding, (2) large mutual and self-capacities of the windings. To get a basis for design it is essential to examine the theory of the instrument. This indicates that the resistance of the secondary winding should be small as also should the self and mutual capacities. It was not until the advent of Mr. S. Butterworth's classical analysis of coil resistance,* that satisfactory radio frequency intervalve transformers were constructed. The complete theory in which self and mutual capacity effects are embodied is somewhat extensive and uninteresting, the analysis serving to mask the physical

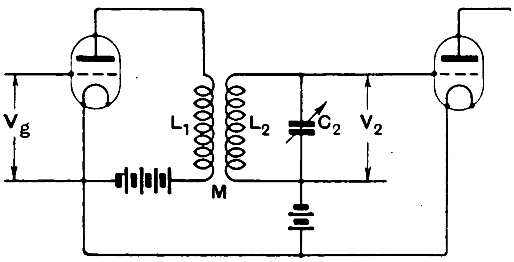


Fig. 1. *Showing radio-frequency transformer connections with neutrodyne arrangement omitted.*

significance of the problem. Moreover, it is proposed herein to make the subject more presentable by neglecting these capacities. Practical measurements show that, provided care is exercised in the design, *e.g.*, the primary should not be made of thick wire closely coiled, this assumption does not lead to serious errors.*

The analysis is equally valid for screened valves and for neutrodyned three-electrode valves. The usual circuit in which the neutrodyne connections are omitted is shown in Fig. 1. This is reduced to an equivalent

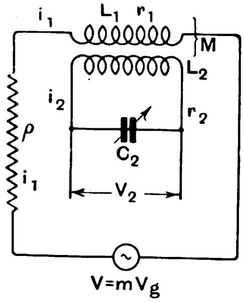


Fig. 2. *Equivalent circuit of valve* V_1 *of Fig.* 1. $V = mV_g = g\rho V_g$ *where "g" is the mutual conductance.*

circuit in Fig. 2. Needless to say, we shall neglect feed-back effects due to the valves preceding and succeeding the transformer.

From Fig. 2 we obtain the following circuital equations :—

$$(r_1+\rho)i_1 + j\omega L_1 i_1 + j\omega M i_2 = V = mv_g \ldots \quad (1)$$

$$r_2 i_2 + j\omega L_2 i_2 + j\omega M i_1 - \frac{j i_2}{\omega C_2} = 0 \quad \ldots \quad (2)$$

From (1)

$$i_1(\rho + j\omega L_1) + i_2 \,.\, j\omega M = V \quad \ldots \quad \ldots \quad (3)$$

since r_1 is small compared with ρ.

From (2)

$$i_1 \,.\, j\omega M + i_2(r_2 + j\omega L_2 - j/\omega C_2) = 0 \quad \ldots \quad (4)$$

Solving equations (3) and (4) we have :—

$$i_2\{(-\omega^2 L_1 L_2(1-k^2) + \rho r_2 + L_1/C_2) + j(\omega L_2 \rho - \rho/\omega C_2)\} = -j\omega M V \ldots \quad (5)$$

Where $M^2 = k^2 L_1 L_2$ and we neglect $\omega L_1 r_2$ in comparison with $\omega L_2 \rho$.

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* *E.W. & W.E.*, Vol. 3, p. 203.

* The mutual capacity can be represented approximately as an equivalent secondary capacity.

From (5) we get (scalar value)

$$i_2 = \frac{\omega MV}{\{(-\omega^2 L_1 L_2(1-k^2)+\rho r_2 + L_1/C_2)^2 + [\rho/\omega C_2(\omega^2 L_2 C_2 - 1)]^2\}^{\frac{1}{2}}} \quad (6)$$

At resonance $\omega^2 L_2 C_2 = 1$, so that (6) becomes

$$i_2 = \frac{\omega M C_2 V}{k^2 L_1 + \rho r_2 C_2} \quad \ldots \quad (7)$$

The voltage across the grid and filament of the succeeding valve is equal to that across C_2. At resonance this voltage is

$$V_2 = i_2/\omega C_2 = \frac{MV}{k^2 L_1 + \rho r_2 C_2} = \frac{k(L_1 L_2)^{\frac{1}{2}}}{k^2 L_1 + \rho r_2 C_2} \quad (8)$$

Putting $L_2/L_1 = s^2$, equation (8) becomes

$$V_2 = \frac{skL_2 V}{k^2 L_2 + \rho r_2 C_2 s^2} = \frac{L_2 V}{(k/s)L_2 + s/k(\rho r_2 C_2)}$$

$$= \frac{L_2 V}{aL_2 + \frac{\rho r_2 C_2}{a}} \quad \ldots \quad \ldots \quad (9)$$

where $a = k/s$.

In practice the values of L_2 and C_2 are fixed according to the waveband to be covered by the receiver. For any given frequency this fixes the value of r_2. As the wavelength varies, say from 300 to 500 metres, r_2 decreases in value, but C_2 increases. In practice the product λr_2 over the range 300 to 500 metres is substantially constant for a low loss coil. But $\lambda = 1885\ (L_2 C_2)^{\frac{1}{2}}$ so that $r_2 C_2^{\frac{1}{2}}$ is constant and therefore the product $C_2 r_2$ increases with the wavelength. Thus the transformer design must be based on some particular wavelength. In equation (9) everything is constant except a. Differentiating (9) with respect to "a" we find that the maximum value of V_2 is obtained when the two terms in the denominator are equal, that is when

$$aL_2 = \frac{\rho r_2 C_2}{a}$$

or

$$a = \left(\frac{\rho r_2 C_2}{L_2}\right)^{\frac{1}{2}} \quad \ldots \quad (10)$$

Now at resonance the impedance of the secondary winding of the transformer is a dynamic resistance whose value is

$$R_2 = L_2/r_2 C_2 = \omega^2 L_2^2/r_2.$$

Substituting this value of R_2 in (10) we obtain the optimum value of

$$(k/s) = a = (\rho/R_2)^{\frac{1}{2}} \quad \ldots \quad (11)$$

Since $a = k/s$ it follows that if either k or s is fixed, the optimum value of the variable one is found from (10). Thus when s is fixed, the optimum value of

$$k = s\,(\rho/R_2)^{\frac{1}{2}} \quad \ldots \quad \ldots \quad (12)$$

Also the optimum value of

$$s\ (k = const.) = k\,(R_2/\rho)^{\frac{1}{2}} \quad \ldots \quad (13)$$

Substituting the value of a from (11) and also $\frac{L_2}{r_2 C_2} = R_2$ in (9) we find

$$V_2 = V/2\left(\frac{R_2}{\rho}\right)^{\frac{1}{2}} = \frac{mv_g}{2}\left(\frac{R_2}{\rho}\right)^{\frac{1}{2}} \quad \ldots \quad (14)$$

which is the maximum possible value of V_2.

In designing the transformer if we know k it is possible to find the correct value of s by calculation; also s can be found experimentally, using a tapped primary. Conversely, if we know s it is possible to find k not only by calculation, but by experiment. Care, however, must be exercised that the conditions, *i.e.*, the various coefficients or factors involved, are not such that a value of k greater than unity and an absurd value of s is required to give the maximum transformer amplification. In other words, one cannot wind a primary indiscriminately and with *any* type of valve, and expect to find the optimum coupling.

Equation (13) can be written

$$V_2 = A\frac{m}{\rho^{\frac{1}{2}}} \quad \ldots \quad \ldots \quad (15)$$

where $A = \dfrac{v_g R_2^{\frac{1}{2}}}{2}$

By taking a certain coil at a definite frequency so that A remains constant, we can, by calculating the ratio $m/\rho^{\frac{1}{2}}$, obtain some idea of the utility of various valves in combination with transformers designed for maximum magnification. This has been done in Table I. where a series of values of this ratio are given for a variety of valves. The valve parameters are those published by the manufacturers, but of course one would expect to find variations in practice. It is clear that, except in the case of the DE5, the higher the internal A.C. valve resistance the greater is the ratio $m/\rho^{\frac{1}{2}}$ and therefore the magnification. For completeness the optimum values of s* (assuming $k=1$) have

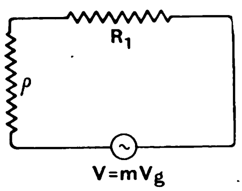
* Under certain conditions s may be considered as the turns ratio. For these transformers the inductance ∝ turns^2×a variable parameter depending on length of coil, etc., so that s is not the turns ratio. As an easy way of viewing the problem s can be regarded as approximating to the turns ratio.

been given, also the maximum magnification with this ratio. If k is less than unity s decreases, *i.e.*, the primary inductance increases. From the table we also see that s decreases as the valve resistance increases. This is necessary so that the equivalent primary impedance of the transformer suits the valve. This can be seen more clearly by the aid of Fig. 3 which represents the equivalent primary circuit of valve and transformer. The transformer impedance

TABLE I.

DATA FOR VARIOUS VALVES AND TRANSFORMERS.

Valve.	ρ	$m/\rho^{\frac{1}{2}}$	S (optimum).	Max. magnification per stage.
DE3	2.2×10^4	4.7×10^{-2}	4.5	15.5
DE3B	5×10^4	7.6×10^{-2}	3	25
DE5	7×10^3	8.4×10^{-2}	8	28
DE5B	3×10^4	11.6×10^{-2}	3.8	38
DEH610	6.5×10^4	15.7×10^{-2}	2.6	52



$$R_1 = \frac{k^2}{s^2} R_2 = \frac{k^2}{s^2} \cdot \frac{L_2}{C_2 r_2}$$

Fig. 3. *Showing equivalent primary circuit of transformer and valves. The optimum value of* $R_1 = \rho$.

at resonance is a dynamic resistance R_1 and the formula for the magnification is identical with that of a resistance-coupled stage. Thus magnification in anode circuit $= m \,.\, R_1/(\rho + R_1)$ where R_1 is the equivalent primary resistance. The voltage on the grid of the succeeding valve is

$$V_2 = mv_g \left(\frac{R_1}{\rho + R_1}\right) \times \text{equivalent transformer ratio} \quad (16)$$

The value of R_1 and the ratio can be found by transforming equation (9) which becomes

$$V_2 = mv_g \,.\, \frac{a^2 R_2}{a(\rho + a^2 R_2)} \quad \ldots \quad (17)$$

where $a = k/s$ and $R_2 = L_2/C_2 r_2$.

Thus we see that

$$R_1 = a^2 R_2 = \frac{k^2}{s^2} R_2$$

and that the equivalent transformer ratio is s/k. Thus (16) can be written

$$V_2 = mv_g \,.\, s/k \left(\frac{R_1}{\rho + R_1}\right) \quad \ldots \quad (18)$$

From (11) the optimum value of k/s is $(\rho/R_2)^{\frac{1}{2}}$. Since

$$R_1 = \frac{k^2}{s^2} R_2$$

the optimum value of R_1 is $\rho R_2/R_2 = \rho$, *i.e.*, the magnification is a maximum when the dynamic primary resistance is equal to the internal valve resistance—which we might have anticipated. To secure this condition the value of s must vary with the internal valve resistance.

Screened Valves.

With a screened valve both the values of "m" and "ρ" are considerably larger than for a three-electrode valve. The data pertaining to a screened valve and a suitable radio-frequency transformer are given in Table II. The valve taken is that already described by the author in the *Wireless World*.* It is assumed to work with a grid bias of about — 1, an anode voltage of 120, and a screen voltage of 80, at which point on the characteristic the internal resistance and magnification factor are approximately 2×10^5 ohms and 100 respectively.

TABLE II.

DATA REGARDING SCREENED VALVE AND TRANSFORMER.

Valve.	ρ (internal resist.	$m/\rho^{\frac{1}{2}}$	S (optimum).	Magnification per stage.
Screened Valve S625	2×10^5	2.24×10^{-2}	1.48	70

The data in Table II. show the superiority of the screened valve over the three-electrode valves cited in Table I. There is one point of importance to which reference must be made, namely, the stability of the circuit with a magnification of 70. Assuming a cascaded amplifier, this valve would, at wavelengths from 300 to 500 metres, be too high for stability, so that the transformer would require amended design with this in view. If the aerial loading coil were coupled

* 31st August, 7th and 14th September, 1927.

direct to the grid of the valve this might in some cases ensure sufficient damping to prevent self-oscillation due to feed-back. It is certain, however, that precautions should be taken to screen the transformer electrostatically and electromagnetically from the grid and aerial circuits.

Screened Valve and Tuned Anode.

The comparatively small value of the turns ratio for a screened valve, viz., 1.48, makes one curious to know whether the transformer has an advantage over the plain tuned anode. The magnification with the latter, using our secondary low loss coil, is found from equation (17) by putting $a=1$. This gives

$$V_2 = mV_g\left(\frac{R_2}{\rho+R_2}\right) \quad \dots \quad (19)$$

Taking the magnification ratio $\frac{\text{Transformer}}{\text{Tuned anode}}$ we get from (14) and (19)

$$\frac{Tr}{T.A} = \frac{\rho + R_2}{2(\rho R_2)^{\frac{1}{2}}}$$

Putting $L_2 = 200\mu\text{H}$ and $r_2 = 2$ ohms at 7.5×10^5 cycles (400m.) we find $R_2 = 4.4 \times 10^5$.

Hence, with $\rho = 2 \times 10^5$ the ratio $Tr/T.A. = 1.08$. Thus the best transformer has an advantage in magnification of only 8 per cent. over the tuned anode.* Which device is preferable is largely a matter of design. The tuned anode necessitates an additional condenser and grid-leak. To secure maximum amplification the losses in these should be a minimum. On the other hand, the amplification with low loss coils is too high for stability unless the aerial damping is adequate.† Hence the losses in leak and condenser are of less importance in practice.

Selectivity of Transformer.

A transformer gives a gain in selectivity over a tuned anode (*barring feed-back effects*), but this gain is not so marked with the screened valve as it is with the three-electrode valve. The equivalent primary capacity is C_2s^2 when k is unity. Thus the primary circuit is virtually a tuned anode of inductance L_1 and capacity C_2s^2, as shown in Fig. 4. The capacity being larger than C_2 means enhanced selectivity over a tuned anode using the same (secondary) inductance and capacity. This was shown in detail in a former article in this Journal.* With a screened valve s^2 (taking k as unity) is a fraction of that with a three-electrode valve, so that the primary condenser is greater in the latter case. Thus the selectivity of the transformer is comparatively more marked with the three-electrode valve than with a screened valve.

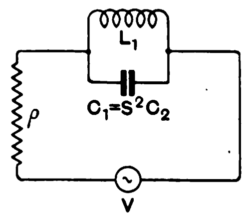


Fig. 4.
Equivalent primary circuit of transformer when k = 1.

Since the dynamic resistance $R_2 = L_2/C_2r_2$, it is clear that its value at any given frequency decreases with increase in the condenser C_2 ($L_2C_2 = \textit{const.}$). By reducing R_2 in this way it is possible to stabilise a screened valve with tuned anode and at the same time enhance the selectivity. Another particularly effective method is to increase the grid bias. In practice, owing to variable condensers usually being limited in capacity for covering a certain waveband, it may be preferable to use a transformer with a value of s^2 larger than the optimum, *i.e.*, too large a turns ratio. The equivalent primary dynamic resistance is reduced owing to the increase in equivalent primary capacity. The variation in anode voltage is decreased as also is the valve damping, whilst the selectivity is enhanced. In point of fact, a transformer with a tapped primary is very useful in practice, for it is possible to find by experiment a ratio (*i.e.*, value of s^2) which gives stability. It must be realised that when there is a tendency to self-oscillation with a low transformation ratio the increased selectivity due to a higher ratio may not be appreciably apparent. Where a high magnification per stage is imperative there is, of course, no reason why the neutrodyne principle should not be used, although this defeats the object for which the screened valve was designed.

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* The ratio, of course, for any given valve depends on R_2. The value of r_2 in a receiver might be greater than 2 ohms, owing to losses due to neighbouring components. Some valves received recently have a larger internal resistance than that quoted here. Moreover, the calculated data apply to this particular valve and are not standard.

† See *Wireless World*, 31st August and 7th September, 1927.

* *E.W. & W.E.*, September, 1926.

The Properties of the Circle Diagram for Telephonic Frequency Intervalve Transformers.

By Professor Felix E. Hackett, Ph.D. (Dublin).

AN important advance in the theory of the performance of intervalve transformers was made by the work carried out in the National Physical Laboratory recorded by Mr. Dye in a most interesting series of articles.*

The investigation was directed to examine the performance of the transformer under conditions of use by measuring the effective primary resistance and reactance of the transformer suitably connected over a range of audio frequencies. It was somewhat of a surprise to find that plotting the resistance against the reactance a good circle was obtained (Fig. 2). This result suggested that the effect of the transformer could be represented by a simple circuit. It was shown how the values of an inductance (L),

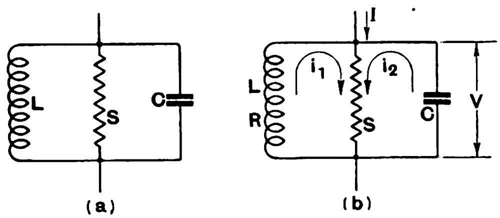


Fig. 1.

a small condenser (C) and a large resistance (S) all in parallel could be determined which would be equivalent to the action of the transformer. It is by no means easy to carry out the measurement of an inductance of many henries with a resistance of many thousands of ohms, but the way in which the simple circuit supplied all the theoretical demands is convincing proof that the difficulties were surmounted and accuracy attained.

The calculation of the constants of the equivalent circuit was made by a method of continued approximation based on observations at two frequencies. In this note another method of calculation is submitted which is somewhat simpler, as it avoids the cumbersome expressions which are commonly used when dealing with parallel circuits. It has also the advantage of making use of the whole range of observations so that there is greater precision in the result.

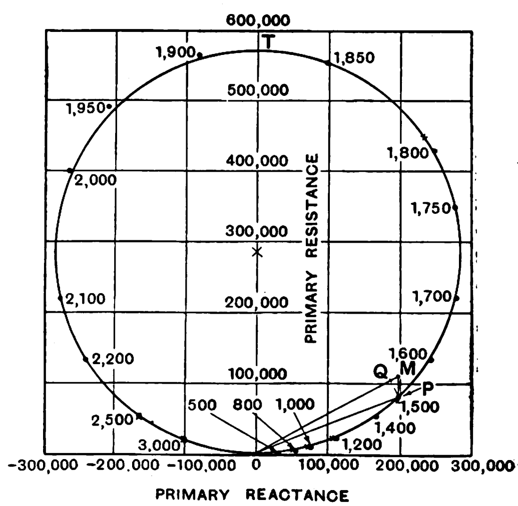


Fig. 2.

The Inductance and Equivalent Capacity of a Transformer.

We shall, in the first instance, illustrate the method by applying it to the simplest kind of circuit, Fig. 1(a), which can give a circle diagram and then to the circuit, Fig. 1(b), which was found to represent the observations more closely. The notation in Dye's paper is modified slightly by writing Y for the effective resistance instead of R_0 and X for the effective reactance instead of $L_0\omega$.

From the usual formula for parallel circuits we have for Fig. 1 (a)

$$\frac{1}{Y+jX} = \frac{1}{jL\omega} + \frac{1}{S} + jC\omega$$

* Dye. *E.W. & W.E.*, Sept., Oct., Nov., 1924.

or $$\frac{Y-jX}{Y^2+X^2} = \frac{-j}{L\omega} + \frac{1}{S} + jC\omega$$

Hence $$\frac{Y}{X^2+Y^2} = \frac{1}{S} \quad \ldots \quad \ldots \quad (1)$$

$$\frac{X}{X^2+Y^2} = \frac{1}{L\omega} - C\omega \quad \ldots \quad (2)$$

The essential part of the method consists in retaining the equations in this form instead of, as usual, solving for X and Y. If we plot Y against X (1) shows that the graph is a circle whose equation is $SY = X^2+Y^2$, touching the X-axis at the origin and having its centre on the Y-axis at the point $S/2$. Its diameter is easily seen to be S the value of Y (Y_r) when the circuit is non-reactive. This occurs at the point of resonance when $LC\omega^2 = 1$ from (2).

"Such a circle although approximately representing the performance of the primary of transformer cannot quite do so since the inductance L has in practice a resistance R which is shown by the fact that the actual graph does not touch the X-axis at the origin but gives a relatively small value of R corresponding to frequency 0. Now this resistance R, although of little consequence to the lower portion of the circle, has a considerable influence on the diameter of it. A further effect is to cause the circle to be displaced horizontally by a small amount so that its centre lies to the left of the R-axis. The experimental results are sufficiently accurate to show this as will be seen from a close inspection of the points in Fig. 2."*

A closer approximation to the experimental and the actual case is given by Fig. 1 (b), where the inductance now includes a resistance R.

Before discussing this circuit we note that on writing $1/L\omega - C\omega = P$

$$\frac{X}{X^2+Y^2} = \frac{1}{L\omega} - C\omega = P$$

It will now be shown that notwithstanding the inclusion of R the value of P can still be calculated by this equation to a very close approximation. The ease of this calculation enables a series of values of P for different frequencies to be obtained without much trouble. These can then be used to find L and C.

* Dye. *Loc. cit.*

Returning to the circuit 1(b) we have

$$\frac{1}{Y+jX} = \frac{1}{R+jL\omega} + \frac{1}{S} + jC\omega$$

giving,

$$\frac{Y}{X^2+Y^2} = \frac{R}{R^2+L^2\omega^2} + \frac{1}{S} \quad \ldots \quad (3)$$

$$\frac{X}{X^2+Y^2} = \frac{L\omega}{R^2+L^2\omega^2} - C\omega \quad \ldots \quad (4)$$

The next step is the deduction of L and C from the observed values of the effective resistance Y and effective reactance X at different frequencies. This is easily done by re-writing (4) thus

$$\frac{X}{X^2+Y^2} = -\frac{R}{L\omega} \cdot \frac{R}{R^2+L^2\omega^2} + \frac{1}{L\omega} - C\omega$$

Putting $R/L\omega = a$ it follows that we have

$$P = \frac{X}{X^2+Y^2} + \frac{a}{R(1+a^{-2})} \doteqdot \frac{X}{X^2+Y^2} \quad (5)$$

Trial calculations using the values obtained by Dye show that the error in neglecting the second term is less than 0.1 per cent. For instance, taking $L =$ 8.68 H, $R = 1{,}000$ ohms when $\omega = 9{,}424$, $a = 1/83$, we find that the second term is 2×10^{-9}, while the first term inserting $X = 198{,}500$ ohms and $Y = 85{,}000$ ohms is 4.25×10^{-6}. The error in taking P as equal to the first term is about 0.05 per cent. It obviously diminishes for higher frequencies.

We can then use the approximate formula (5) with confidence. It has been applied to the calculation of a series of values of P from the table of effective resistances and reactances given by Dye* for frequencies ranging from 50 to 3,000. If we write $\omega = 2\pi n$

$$P = \frac{1}{L\omega} - C\omega = \frac{1}{2\pi L n} - 2\pi C n$$

or $$Pn = -2\pi C . n^2 + (2\pi L)^{-1}$$

Plotting Pn against n^2, we get a straight line whose intercept is $(2\pi L)^{-1}$ and whose slope is $-2\pi C$. This has been done in Fig. 3.

The points lie closely on a straight line where it passes through the resonance even frequency, showing that the equivalent

* *E.W. & W.E.*, Sept., 1924, Table I, p. 695.

simple circuit represents very closely indeed the performance of an intervalve transformer.

By reading from the graph or by a corresponding calculation from the observations to have greater accuracy, we find

$L = 9.10\ (8.68)$ H. $C = 820\ (825)\mu\mu$F.

The values in brackets are those recorded by Dye, which were obtained by a continued approximation from observations at two frequencies. The origin of the greater discrepancy for L has not been investigated.

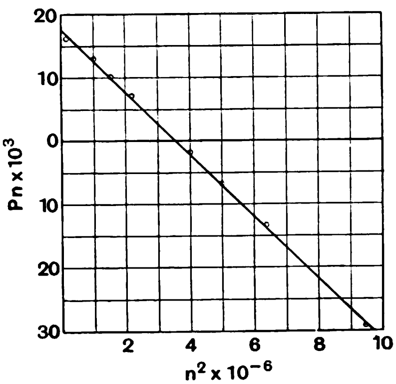


Fig. 3.

The Diameter of the "Circle."

The results of the general examination of the performance of an intervalve transformer is then conveniently represented by means of the diagram of Fig. 2, which we have seen is practically a circle. The intercept on the axis, corresponding to the diameter of a circle in the simplest case (1A), is the important constant. It is really the effective resistance Y_r when the equivalent circuit (1B) is non-reactive ($X = 0$). If we write (4) in the form

$$\frac{X}{X^2+Y^2} = \frac{\omega L}{R}\left[\frac{R}{R^2+L^2\omega^2} - \frac{RC}{L}\right] \quad (7)$$

and put the expression in the brackets equal to zero, by substituting in (3), we have

$$\frac{1}{Y_r} = \frac{1}{S} + \frac{RC}{L} \quad \ldots \quad \ldots \quad (8)$$

The value of Y_r can be read off from the graph and using the values of C and L, S can be found, assuming that R is the D.C. resistance of the primary. This relation has been used by Dye to interpret the effects of added capacity or shunt resistance in a series of illustrations. It may be noted that the frequency ω_r at which the circuit is non-reactive is given by

$$LC\omega^2_r = 1 - CR^2/L$$

The Circle-Diagram.

This interesting method of treating the problem of the intervalve transformer may not obtain its due appreciation owing to a difficulty hitherto omitted from the discussion. The circle-diagram is not accurately a geometrical circle. We have yet to show how it deviates from the geometrical form and why it is so close to it. The graphical construction below exhibits the relationship to the circle perhaps more clearly, but the equations (3) and (7) enable us to make the account more complete. Combining them, we derive

$$\frac{Y - XR/L\omega}{X^2+Y^2} = \frac{1}{S} + \frac{RC}{L} = \frac{1}{Y_r}$$

or $$X^2 + Y^2 - YY_r + XY_r R/L\omega = 0 \quad (9)$$

From this equation, we can deduce the characteristics of the graph given by plotting reactance (Y) against resistance (X). Since frequencies below 1,000 are confined to a small portion of the circle-diagram near the origin (Fig. 2), we see that for almost the whole graph $R/L\omega$ does not exceed 1/50 and decreases in value round the circumference. For any small range of frequencies equation (9) shows that the graph is a circle with its centre $Y_r/2$ from the X-axis but displaced to the left of the Y-axis by $Y_rR/2L\omega$. The amount of this displacement is therefore less than 1/50 of the radius. Small as it is, the fact has been noted by Dye in the quotation already given. It does not influence the radius to any appreciable extent which may therefore be taken as constant and equal to $Y_r/2$.

Though it is therefore sufficiently accurate to refer to the graph as a circle, there are two points of difference which it is important to notice as they may occasion difficulties to anyone who assumes in consequence that it has all the properties of a circle. In the present instance these differences are insignificant, but in other circuits of a similar kind they might be perceptible. The graph is not closed; it begins at $Y = R$ for frequency 0 and ends at $Y = 0$ for frequency ∞. Since R has a relatively small

value, this is not apparent in Fig. 2. Again owing to the way in which the curve is described the diameter is not truly the maximum value of Y which is really a little to the left of the axis and is 0.01 per cent. greater than Y,—a truly negligible quantity.

The Crank Diagram.

As there are some who prefer to use crank or vector diagrams, we shall conclude this note by showing how some of the foregoing results may be derived by this method.

Let us take I as the "line" current, and i_1 and i_2 as the cyclic currents through the inductance and condenser in Fig. 1(B). The sum of the vectors OA, AB and BC represents the potential drop (V) over the resistance S due to the currents I, i_1 and i_2, Fig. 4. If we took I as a constant and equal to unity, OC would be the effective impedance and would therefore be given by plotting resistance along OA and reactance normal to OA. We have to show that the point C moves nearly in a circle.

Produce OC to cut BA in D; draw CE parallel to BA cutting OA in E. Then we can prove that E is a fixed point.

Since the voltage over the condenser is V, OC represents $ji_2/C\omega$ and is normal to BC.

The inductive drop in L has a phase angle α with the total drop V. Its vector is at right angles to its current vector AB and OC is also normal to BC so that the angle CBA is α. We have

$$CD = CB\tan\alpha = Si_2 \cdot \frac{R}{L\omega}$$

$$OC = \frac{i_2}{C\omega}$$

or

$$\frac{CD}{OC} = \frac{SRC}{L} = \frac{EA}{OE}$$

This proves that E is a fixed point for all values of V corresponding to a constant value of I which may conveniently be taken as unity. The angle at C is $\pi/2 + \alpha$ and differs but slightly from a right angle since α is about 1°. (In the diagram, for clearness of representation, it is taken about 9°.) The point C will, therefore, lie nearly on a circle described on OE as a diameter.

When the circuit is non-reactive, the point C moving on the circle coincides with E. OE then represents Y,I, where

$$\frac{SI}{Y,I} = \frac{OA}{OE} = 1 + \frac{EA}{OE} = 1 + \frac{SRC}{L}$$

This equation gives the graphical derivation of the "diameter of the circle" and it can be put in the same form as (8).

Notation.

Fig. 4 has been drawn using the accepted anti-clockwise rotation of vectors. This leads to a curious difference from Fig. 2. To make the diagrams correspond we have to turn Fig. 4 through a right angle and look at it through the paper. This difference would be removed if in Fig. 2 reactance

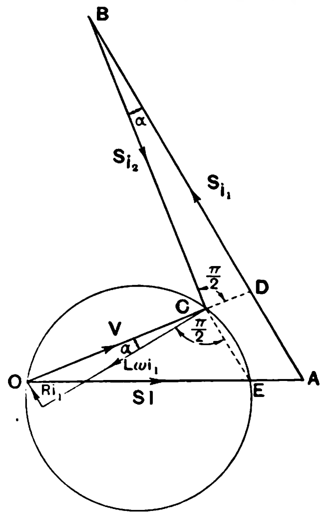


Fig. 4.

had been plotted vertically so that the diameter of the circle and resistance were horizontal. On the other hand, this method would have the inconvenience of plotting reactance denoted by X along the Y-axis. The anti-clockwise convention and the X-notation for reactance are, however, firmly entrenched in current literature. It is, perhaps, asking for the moon, to hope that the present conventions may be altered so that Y could be written for reactance and X used as an alternative to R for resistance. Impedance would then be written $Z = X + jY$ which would be closer to common mathematical usage. The writer has much pleasure in acknowledging the co-operation of Mr. P. O'Callaghan, A.R.C.Sc.I., in the preparation of this article.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 566 *of September issue.*)

PART III (CONTINUED).

12. Vector Functions and the Differentiation of Vectors.

NOW we come to a section which links up directly with alternating current phenomena and thus with wireless telegraphy.

Let $\mathbf{v}$ be a vector of magnitude v and direction θ relative to the fixed unit vector of reference ν parallel to the bottom edge of the paper, *i.e.*,

$$\mathbf{v} \cdot \nu = v \cos \theta$$

Now either or both of v and θ may depend in some specified manner on some independent variable, t for instance (time), being functions of the independent variable in the ordinary sense of the word. Thus if v is $f(t)$ and $\theta = \phi(t)$,

$$\mathbf{v} \cdot \nu = f(t) \cos \phi \ (t)$$

and this equation completely defines the vector. Two important special cases are

$$\mathbf{v} \cdot \nu = v_0 \cos \omega t$$

and $$\mathbf{v} \cdot \nu = v_0 \epsilon^{-kt} \cos \omega t$$

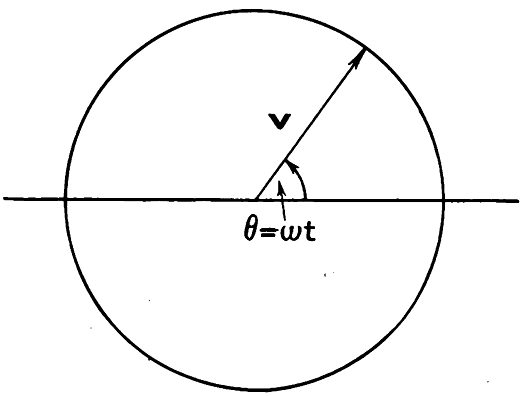


Fig. 32.

In the first case the vector is constant in magnitude and rotates with constant angular velocity (ω radians per second), and in the second case the magnitude of the vector decreases exponentially while it rotates with constant angular velocity ω. These vectors are illustrated in Figs. 32 and 33. The locus of the end of the first vector is a circle and that of the second an

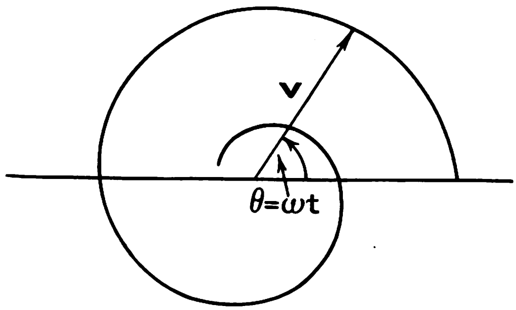


Fig. 33.

equiangular spiral. The reason for the latter name will appear later. It has already been pointed out that a vector of the first type can be used to represent an alternating current or potential difference. Similarly a vector of the second type can be used to represent what is known as a "damped oscillation," the word "damped" being used in the sense of "decreasing"—presumably by derivation from the effect of water on a fire.

Leaving these special cases for a moment, consider the perfectly general case illustrated in Fig. 34, where the variation of the vector is such that its end point moves along the dotted line. Let OV and OV' represent the vector at the instants t and $t + \delta t$. If $\delta\mathbf{v}$ be the change in $\mathbf{v}$ in the interval δt, then OV' is the vector $\mathbf{v} + \delta\mathbf{v}$, whence it follows that VV' represents the vector $\delta\mathbf{v}$. Now the differential coefficient of $\mathbf{v}$ with respect to t is defined in exactly the same way as in the corresponding case of a scalar function, *i.e.*,

$$d\mathbf{v}/dt = \underset{\delta t \to 0}{lt.}\ \delta\mathbf{v}/\delta t$$

The first thing to notice is that the D.C. of a vector is a vector, since $\delta\mathbf{v}$ is a vector. It therefore has both magnitude and direction. Further VV' is a chord of the locus and it is easy to see that in the limit when t tends to zero this chord will coincide in direction with the tangent to the locus at the point V. The direction of the vector $d\mathbf{v}/dt$ is thus the direction of the tangent to the locus of $\mathbf{v}$ at the instant t.

For the complete specification of $d\mathbf{v}/dt$, *i.e.*, for the determination of the scalar product $(d\mathbf{v}/dt).\mathbf{v}$, it is necessary to know both

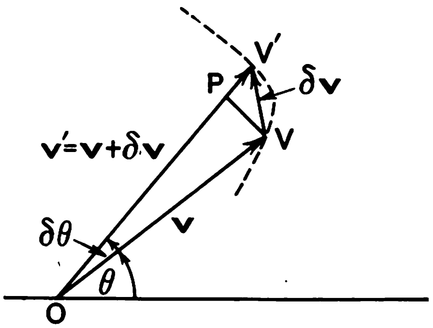


Fig. 34.

its magnitude and direction. These will obviously depend on the nature of the time variation of the magnitude and direction of the vector $\mathbf{v}$, and the vector $d\mathbf{v}/dt$ can be expressed very simply in terms of these two separate variations. On OV' mark the point P such that $OP=OV$ in magnitude. Then PV' represents the change in the magnitude of $\mathbf{v}$. Further, the angle POV or $\delta\theta$ represents the change in the direction of $\mathbf{v}$. The vector $\delta\mathbf{v}$ or VV' is the sum of the vectors VP and PV'. Let $\mathbf{v}_1$ be the unit vector in the direction of $\mathbf{v}$, *i.e.*,

$$\mathbf{v} = v\mathbf{v}_1 \quad \text{or} \quad \mathbf{v}_1 = \mathbf{v}/v$$

(see Para. F, Section 10, June, 1927). The magnitude of VP is approximately $v\delta\theta$ and its direction is approximately perpendicular to $\mathbf{v}$. The unit vector perpendicular to $\mathbf{v}$ is $j\mathbf{v}_1$, or $j\mathbf{v}/v$. As a vector therefore VP can be written approximately

$$VP = v\delta\theta\, j\mathbf{v}/v$$

Again the magnitude of the vector PV' is δv, and if $\delta\theta$ is very small its direction will be very approximately that of $\mathbf{v}$. As a vector therefore it is approximately $\delta v\mathbf{v}/v$. We have thus the approximate equation

$$\delta\mathbf{v} = \delta v\ (\mathbf{v}/v) + jv\delta\theta(\mathbf{v}/v)$$

and dividing through by δt

$$\frac{\delta\mathbf{v}}{\delta t} = \frac{\delta v}{\delta t}\frac{\mathbf{v}}{v} + jv\frac{\delta\theta}{\delta t}\frac{\mathbf{v}}{v}$$

$$= \left(\frac{1}{v}\frac{\delta v}{\delta t} + j\frac{\delta\theta}{\delta t}\right)\mathbf{v}$$

So far this is an approximation only. But notice that all the approximations are such that the statements become more and more correct as δt decreases in magnitude and become exact in the limit when δt tends to zero. All the statements could be made exact with vanishing differences, but this rigid demonstration would take up rather a lot of valuable space. In the limit when δt tends to zero we have

$$\frac{d\mathbf{v}}{dt} = \left(\frac{1}{v}\frac{dv}{dt} + j\frac{\delta\theta}{\delta t}\right)\mathbf{v}$$

which determines $d\mathbf{v}/dt$ completely if dv/dt and $d\theta/dt$ are known. In general $d\mathbf{v}/dt$ is thus expressible in the form $(a+jb)\mathbf{v}$ where a and b are known functions of t.

The expression assumes a very simple form in the two special cases mentioned above. In the first, since the vector is constant in magnitude, dv/dt is zero. Also, since $\theta=\omega t$, $d\theta/dt=\omega$ and is a constant. Therefore for a vector of constant magnitude rotating with constant angular velocity ω

$$d\mathbf{v}/dt = j\omega\mathbf{v}$$

a vector perpendicular to $\mathbf{v}$ and ω times as large. Geometrically this expresses the fact that the tangent to a circle is perpendicular to the radius. Notice that

$$\frac{d^2\mathbf{v}}{dt^2} = j\omega\frac{d\mathbf{v}}{dt} = (j\omega)^2\mathbf{v} = -\omega^2\mathbf{v}$$

and in general

$$d^n\mathbf{v}/dt^n = (j\omega)^n\mathbf{v}$$

For the second case, that of a vector of exponentially decreasing magnitude rotating with constant angular velocity, $d\theta/dt$ is ω as before,

and since $\quad v = v_0\epsilon^{-kt}$

$$dv/dt = -kv_0\epsilon^{-kt} = -kv$$

so that $\quad \dfrac{1}{v}\dfrac{dv}{dt} = -k$

Therefore $\dfrac{d\mathbf{v}}{dt}=(-k+\omega j)\mathbf{v}$

and in general $\dfrac{d^n\mathbf{v}}{dt^n}=(-k+\omega j)^n\mathbf{v}$

(Notice that since $d\mathbf{v}/dt=(-k+\omega j)$ $\mathbf{v}$ the tangent to the locus at $\mathbf{v}$ makes with $\mathbf{v}$ a constant angle $\tan^{-1} - \omega/k$. This is the reason for the name "equiangular spiral" given to this locus.)

These two special cases have very important applications to alternating current theory, and the next two instalments will be devoted to the development of these applications. The matter must be left for the present in favour of a brief account of the companion subject of the differential calculus, *i.e.*, the integral calculus.

13. The Integral Calculus.

Indefinite Integration.

It is rather unfortunate that the word "Integration" is used in two different senses, but this will not matter very much as long as the two ideas are clearly distinguished right from the start. We will take the simpler of the two first, generally called for the sake of distinction "indefinite integration," though there is in fact nothing really indefinite about it. Integration in this sense is simply the inverse of differentiation. The integral with respect to x of any given function of x is the most general function of x of which it is the differential co-efficient. The integral of $f(x)$ with respect to x is written

$$\int f(x)dx^*$$

and its definition is

$$\frac{d}{dx}\left\{\int f(x)\ dx\right\}=f(x)$$

Any function of x which fulfills this definition can be callen *an* integral of $f(x)$ but *the* integral will be taken to mean the most general function which fulfills the definition. For instance $x^{n+1}/(n+1)$ is *an* integral of x^n for

$$\frac{d}{dx}\left(\frac{x^{n+1}}{n+1}\right)=x^n$$

but the most general function which satisfies the condition is

$$\frac{x^{n+1}}{n+1}+C$$

where C is any constant number whatever, so that this will be regarded as *the* integral of x^n. In general any two integrals of the same function can only differ by a constant in view of the definition given above, and the simplest form together with an arbitrary constant will be taken as the integral.

So far so good. It all seems plain sailing. Any table of differential coefficients will immediately furnish an equal number of integrals. For instance, since

$$\frac{d\epsilon^x}{dx}=\epsilon^x,\ \int\epsilon^x dx=\epsilon^x+C$$

Again $\qquad d\log x/dx=1/x$

whence $\displaystyle\int\frac{1}{x}\,dx$ or $\displaystyle\int\frac{dx}{x}=\log x+C$

and so on for all the standard forms of differential coefficient which have already been discussed. Space cannot be spared for the enumeration of them but the reader is advised to make himself familiar with the more important standard forms.

Outside the comparatively few standard forms, however, the difficulties begin. Differentiation is a comparatively simple matter. There is the fundamental formula to start with and rules for combinations of functions to simplify its application. For the inverse process, however, there is practically speaking no guide at all and no such rules for dealing with combinations, no rules that is to say which will inevitably succeed. What then is there to help? Only inspired guesswork. That, of course, lends a certain fascination to the business but its practical limitations need hardly be pointed out.

However, there are one or two general propositions which may simplify matters a little, and these we will briefly pass in review.

* At this point the reader may want to raise an agitation against this apparent violation of the integrity of dy/dx, which he has been told to regard as an inseparable unity. But the "dx" under the integral sign is not, in fact, the dx from dy/dx trying to lead a separate existence. It is merely an agreed shorthand for "with respect to x." Certain text-books use a notation which implies the separate existence of dy and dx, but this is liable to be misleading and the writer has carefully avoided it.

(A) **A Constant Factor.**

It is easy to show that a constant factor can be placed outside the sign of integration, *i.e.*,

$$\int a\,f(x)\,dx = a\int f(x)\,dx$$

for

$$\frac{d}{dx}\int a\,f(x)\,dx = a\,f(x)$$

by definition, and by the rules of differentiation

$$\frac{d}{dx}\,a\int f(x)\,dx = a\,\frac{d}{dx}\int f(x)\,dx$$
$$= a\,f(x)$$

(B) **The Integration of the Sum or Difference of Functions.**

This is comparable with the corresponding proposition in differentiation and can be immediately derived therefrom. If P and Q are functions of x, then by definition

$$d/dx\int (P \pm Q)\,dx = P \pm Q$$

also by the rules of differentiation

$$\frac{d}{dx}\left\{\int P\,dx \pm \int Q\,dx\right\} = \frac{d}{dx}\int P\,dx \pm \frac{d}{dx}\int Q\,dx$$
$$= P \pm Q$$

therefore

$$\int (P \pm Q)\,dx = \int P\,dx \pm \int Q\,dx$$

The proposition can obviously be extended the sum or difference of any *finite* number of functions. As an example

$$\frac{1}{x^2 - a^2} = \frac{1}{2a}\left\{\frac{1}{x-a} - \frac{1}{x+a}\right\}$$

by elementary algebra. Therefore

$$\int \frac{dx}{x^2 - a^2} = \frac{1}{2a}\left\{\int \frac{dx}{x-a} - \int \frac{dx}{x+a}\right\}$$
$$= \frac{1}{2a}\{\log(x-a) - \log x + a)\} + C$$
$$= \frac{1}{2a}\log\frac{x-a}{x+a} + C$$

C being an "arbitrary constant" of integration. This example also illustrates the application of the bundle of sticks idea to integration. Where possible, a complicated function should be separated out into the sum or difference of a number of simpler functions.

(C) **Changing the Variable.**

(i.) Suppose $f(x)$ be expressible in the form $\phi\,(u)(du/dx)$ where u is some other function of x.

For example, $sec^2 x/(a^2 - b^2\,tan^2 x)$. Let $u = b\,tan\,x$. Then $du/dx = b\,sec^2 x$, as already shown, so that

$$\frac{sec^2 x}{a^2 - b^2\,tan\,x} = \frac{1}{b}\,\frac{1}{a^2 - u^2}\,\frac{du}{dx}$$

Now it is easy to show that

$$\int \phi\,(u)\,\frac{du}{dx}\,dx = \int \phi(u)\,du$$

for the R.H.S., which we will call F for short, is a function of a function of x, so that

$$\frac{dF}{dx} = \frac{dF}{du}\,\frac{du}{dx}$$

Also by the definition of integration

$$dF/du = \phi(u)$$

Therefore

$$dF/dx = \phi\,(u)\,\,(du/dx) = f(x)$$

whence by definition

$$F = \int f(x)\,dx$$

For the above example

$$\int \frac{sex^2 x\,dx}{a^2 - b^2\,tan^2 x} = \int \frac{1}{b}\,\frac{1}{a^2 - u^2}\,\frac{du}{dx}\,dx$$
$$= \int \frac{1}{b}\,\frac{1}{a^2 - u^2}\,du$$

$$= \frac{1}{2ab}\,.\log\frac{a-u}{a+u} + C \quad \text{(See } (b) \text{ above)}$$

$$= \frac{1}{2ab}\log\frac{a - b\,tan\,x}{a + b\,tan\,x} + C$$

Thus, inspired guesswork is only required to furnish the substitution $u = b\,\,tan\,\,x$, and thereafter all is plain sailing. This is characteristic of a large number of processes of integration.

(ii.) The substitution of a single letter for a group, as in the above, seems a reasonable method of simplification. In some cases, however, the reverse process can be used with advantage, *i.e.*, the substitution of some simple group for the variable x. Thus in $\int f(x)\,dx$, if we put $x = \phi(u)$, then $f(x)$ becomes a function of the variable u, say $F(u)$, and the integral becomes $\int F(u)\,dx$. Now it can

be shown much as in the previous case that

$$\int F(u)\,dx = \int F(u)\,\frac{dx}{du}\,du$$

and this form will be much simpler than the original if the substitution has been well chosen. For example, in $f(x) = 1/\sqrt{a^2-x^2}$ let $x = a \sin u$. Then

$$\frac{1}{\sqrt{a^2-x^2}} = \frac{1}{\sqrt{a^2-a^2\sin^2 u}} = \frac{1}{a\cos u}$$

Also $dx/du = a \cos u$, therefore

$$\int\frac{dx}{\sqrt{a^2-x^2}} = \int\frac{1}{a\cos u}\cdot a\cos u\cdot du = \int du$$

$$= u + C = \sin^{-1}x/a + C$$

Trigonometrical substitutions of this kind will nearly always afford a simplification in binomial surd functions such as

$$\sqrt{a^2-x^2},\ \sqrt{a+x}/\sqrt{a-x},$$

and so on.

(D) Integration by Parts.

Another very useful dodge is derived from the differential formula—

$$\frac{d(uv)}{dx} = u\frac{dv}{dx} + v\frac{du}{dx}$$

It applies to cases in which the function to be integrated can be put in the form

$$I = \int f(x)\,dx = \int P.R\,dx$$

P and R being functions of x, one of which at least, say R, is easily integrable. Suppose

$$\int R\,dx = Q,\ i.e.,\ R = dQ/dx$$

Then $$I = \int P\frac{dQ}{dx}\,dx$$

Now it can be shown that

$$\int P\frac{dQ}{dx}dx = PQ - \int Q\frac{dP}{dx}dx$$

for, differentiating this equation and remembering the definition of an integral,

$$P\frac{dQ}{dx} = \frac{dPQ}{dx} - Q\frac{dP}{dx}$$

which is the "differential of a product" formula already quoted above. As an example—

$$\int x\cos x\,dx = \int x(d\sin x/dx)\,dx$$
$$= x\sin x - \int\sin x\,dx$$
$$= x\sin x + \cos x + C$$

Or again,

$$\int x\epsilon^x\,dx = \int x(d\epsilon^x/dx)\,dx = x\epsilon^x - \int\epsilon^x dx$$
$$= x\epsilon^x - \epsilon^x + C$$

So much for a brief outline of the subject of "indefinite" integration. The above formulæ are practically all one has to go on. The rest is inspired guesswork of an intuitive kind, but fortunately the intuitive faculty required increases with practice and experience. A few examples are given at the end of this section, but far more should be worked by any serious student, for integration, like genius, is nine parts perspiration to one of inspiration. Examples are easily made up and the work can be made self-checking by differentiation of the result.

14. Definite Integration.

Now we come to the more practically important of the two ideas associated with the word "integration." What we are concerned with now is the evaluation of expressions such as

$$\underset{\delta x\to 0}{Lt.}\ f(a)+f(a+\delta x)+f(a+2\delta x)+\text{etc.}\ \ldots$$
$$f(b-\delta x) + f(b) = \underset{\delta x\to 0}{Lt.}\sum_{x=a}^{x=b} f(x)\delta x$$

i.e., the limit when δx tends to zero of the sum of all terms such as $f(x)\ \delta x$ when x increases by steps of δx from a lower value a to an upper value b.

But first readers will probably want to know how such cumbersome-looking expressions come into practical politics at all. Let Fig. 35 represent $f(x)$ plotted against x for the range a to b of x. It will be assumed that there is no minimum or maximum value of $f(x)$ in this range, *i.e.*, $f(x)$ either decreases or increases uniformly from a to b. If $f(x)$ is not in fact of this character the range can be divided up into sub-ranges in each of which the limitation applies, and the following discussion can then be applied to each of these separately. Suppose we require to calculate the area included between the

ordinates at a and b and the curved line representing $f(x)$. One method that suggests itself is to divide up the area into n strips each of width δx. The area of any strip, such as that shown in the figure, lies between that of the shorter and that of the taller of the two rectangles, *i.e.*, between $y\delta x$ and $(y+\delta y)\delta x$, and the corresponding limits of the total area will be the sums of these

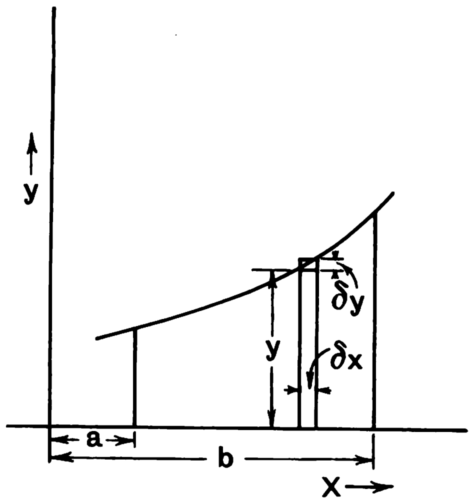


Fig. 35.

expressions for all the strips, *i.e.*, the total area will lie between

$$\sum_{x=a}^{x=b} y\delta x \text{ and } \sum_{x=a}^{x=b} (y\delta x + \delta y\, \delta x)$$

the difference between these limits being

$$\sum_{x=a}^{x=b} \delta y \delta x = \delta x \sum_{x=a}^{x=b} \delta y = \delta x\{f(b) - f(a)\}$$

(since the sum of all the separate increments of y is the difference between the ordinates at a and b, *i.e.*, $f(b)-f(a)$).

It is clear that by making δx sufficiently small either calculation will give the area required to a high degree of accuracy. Further, since the difference between the two is $\{f(b)-f(a)\}\delta x$, which tends to zero as δx tends to zero, it follows that the area is given *exactly* by

$$\underset{\delta x \to 0}{Lt.} \sum_{x=a}^{x=b} y\delta x \quad \text{or} \quad \underset{\delta x \to 0}{Lt.} \sum_{x=a}^{x=b} f(x)\, \delta x$$

Here, then, is one way in which the expression given at the beginning of this section will arise in practice.

Again, suppose we are told that the velocity of a moving body is known as a certain function of time, say $f(t)$, and we are asked to calculate the distance it will travel in the interval between the instants $t=a$ and $t=b$. There is no question of simply multiplying the time interval $b-a$ by the velocity, because the latter is not constant. As in the above case, however, an approximation could be obtained by dividing the interval into a large number of smaller equal intervals δt, calculating the velocity $f(t)$ at the beginning of each interval and multiplying by δt to get the distance travelled in the short interval. Upper and lower limits for the distance travelled could then be calculated for the whole interval precisely as shown above, and the difference between these could be made as little as desired by sufficiently decreasing δt. The exact result would be, as before

$$\underset{\delta t \to 0}{Lt.} \sum_{t=a}^{t=b} f(t)\, \delta t$$

There is therefore very good reason for trying to find some means of evaluating this limit of a sum, and a combination of the ideas of the differential calculus and of indefinite integration will show how this can be done.

It will be assumed that the function $f(x)$ and its integral are finite and continuous over the range a to b of x. Further, let $F(x)$ be the integral of $f(x)$, *i.e.*, $f(x)$ is the differential co-efficient of $F(x)$ with respect to x. The range a to b is divided into the n intervals δx, *i.e.*, $n\delta x = b - a$. By definition

$$\underset{\delta x \to 0}{Lt.} \frac{F(x+\delta x) - F(x)}{\delta x} = f(x)$$

Therefore for any value of δx greater than zero in magnitude

$$\frac{F(x+\delta x) - F(x)}{\delta x} = f(x) + h$$

where h is a quantity which tends to zero when δx tends to zero. This can be written

$$F(x+\delta x) - F(x) = f(x)\delta x + h\delta x$$

By hypothesis this is true for all values of x between a and b, whence

$$\begin{aligned}
F(a+\delta x) - F(a) &= f(a)\delta x + h_1\delta x \\
F(a+2\delta x) - F(a+\delta x) &= f(a+\delta x)\delta x + h_2\delta x \\
F(a+3\delta x) - F(a+\delta x) &= f(a+2\delta x)\delta x + h_3\delta x \\
\text{etc.} \qquad & \text{etc.} \qquad \text{etc.} \\
F(b-\delta x) - F(b-2\delta x) &= f(b-2\delta x)\delta x + h_{n-1}\delta x \\
F(b) - F(b-\delta x) &= f(b-\delta x)\delta x + h_n\delta x
\end{aligned}$$

By addition

$$F(b) - F(a) = \sum_{x=a}^{x=b-\delta x} f(x)\delta x + \delta x \sum h_n$$

Therefore

$$\underset{\delta x \to 0}{Lt.} \sum_{x=a}^{x=b-\delta x} f(x)\delta x = F(b) - F(a) - R$$

where

$$R = \underset{\delta x \to 0}{Lt.} \ \delta x \sum h_n$$

Now the quantities h_n are finite by hypothesis. Let h be the largest value reached by any of them for any value of δx between δx and zero. Then

$$| \delta x \sum h_n | \not> | n \delta x h |$$

(the vertical strokes mean that magnitude only is being considered, and $\not>$ means "not greater than.") Therefore, since $n\delta x = b - a$

$$|\underset{\delta x \to 0}{Lt.} \delta x \Sigma h_n| \not> |\underset{\delta x \to 0}{Lt.} (b-a)h| = |(b-a) \underset{\delta x \to 0}{Lt.} h| = 0$$

since the limit of all the h quantities is zero when δx tends to zero. Therefore, finally, since R is zero,

$$\underset{\delta x \to 0}{Lt.} \sum_{x=a}^{x=b-\delta x} f(x)\delta x = \underset{\delta x \to 0}{Lt.} \sum_{x=a}^{x=b} f(x)\delta x = F(b) - F(a)$$

The expression on the left is usually written in the more compact form

$$\int_a^b f(x) \, dx$$

and is called the "definite integral" (or, in practice, just "the integral") of function x with respect to x from a to b. Thus we have

$$\int_a^b f(x) \, dx = F(b) - F(a)$$

where $F(x)$ is the integral of $f(x)$ with respect to x in the first sense of the word,

i.e., $$F(x) = \int f(x) \, dx$$

In the actual calculation of definite integrals $F(b) - F(a)$ is written

$$\Big[F(x) \Big]_a^b$$

so we have

$$\int_a^b f(x) \, dx = \Big[\int f(x) \, dx \Big]_a^b = \Big[F(x) \Big]_a^b = F(b) - F(a)$$

As an example

$$\int_a^b dx/x = \Big[\log x \Big]_a^b = \log b - \log a = \log (b/a)$$

Notice that there is no need to include the arbitrary constant of integration in $F(x)$ for it would automatically disappear in taking the difference of the limiting values. Notice, further, that

$$\int_a^b f(x) \, dx$$

is not in general a function of x, but is a function of the limits a and b. It will only be a function of x if x or any term depending on x appears in the limits.

15. The Mean Value of a Function.

Another important application of definite integration is the determination of the mean value of a function over a certain range of the variable. In terms of area the mean value of the function is the height of the rectangle of base $(b-a)$ the area of which is equal to that enclosed by the curve $y=f(x)$ and the ordinates at a and b. In terms of the variable velocity example also given above, it would mean the equivalent constant velocity, equivalent in the sense that the moving body would travel the same distance in the same time. In general terms, therefore, the definition of y_m, the mean value of $f(x)$ over the range a to b of x, is

$$(b-a)y_m = \int_a^b f(x) \, dx \quad \text{or} \quad y_m = \frac{1}{b-a} \int_a^b f(x) \, dx$$

Two important special cases are (i.) the mean value of an alternating current $i = \hat{\imath} \sin \omega t$ over a period (*i.e.*, $2\pi/\omega$), and (ii.) the mean value of the square of the same alternating current over the same period. These will be considered later.

Here, then, ends the account of definite integration and, with it, the whole of the general discussion of the mathematical foundations of alternating current analysis. The remaining instalments will be devoted entirely to specific applications to actual problems. The fundamental ideas have been presented in a very condensed form, but the necessarily limited space at my disposal has precluded a very detailed exposition. This very limitation can, however, be turned to good account by any serious student of the subject, who will find in the development of the detail the best possible means of familiarising himself with the important fundamental ideas.

Examples.

1. Given that $\mathbf{v} . \nu = v_0 \epsilon^{kt} \cos(\omega t + \psi)$ find $d\mathbf{v}/(dt$ and $d^2\mathbf{v}/dt^2$ in terms of $\mathbf{v}$ and a vector operator. Also find $(d\mathbf{v}/dt) . \nu$ and $(d^2\mathbf{v}/dt^2) . \nu$.

2. Find the following integrals :—

   i. $\int \frac{dx}{ax+b}$

   ii. $\int \frac{(ax+b)\,dx}{cx+d}$

   iii. $\int \sec x \tan x \, dx$

   iv. $\int \frac{dx}{a^2+x^2}$ (put $x = a \tan \theta$)

   v. $\int \frac{\epsilon^x dx}{1+\epsilon^{2x}}$ (put $\epsilon^x = u$)

3. Integrate by parts :—

   i. $x^2 \log_\epsilon x$

   ii. $(\log_\epsilon x)^2$

   iii. $\tan^{-1} x$

4. Show that :—

   i. $\int_a^b f(x)\,dx = -\int_b^a f(x)\,dx$

   ii. $\int_a^c f(x)\,dx = \int_a^b f(x)\,dx + \int_b^c f(x)\,dx$

5. Find the value of

   i. $\int_0^\pi \sin\theta \, d\theta$

   ii. $\int_0^{2\pi} \sin\theta \, d\theta$

   iii. $\int_0^{2\pi} \sin^2\theta \, d\theta$

   Remember that $\sin^2\theta = \frac{1}{2}(1 - \cos 2\theta)$.

6. Show that the curve $x^2 + y^2 = a^2$ is a circle. Find the area included between the x axis and that part of the curve for which y is positive, and hence show that the area of the whole figure is πa^2.

Answers to Examples in September issue.

1. i. $2ax + b$; $2a$; 0.

   ii. $-(b/x^2) - (2c/x^3)$; $(2b/x^3) + (6c/x^4)$; $-(6b/x^4) - (24c/x^5)$.

   iii. $30 \cos x + 30 \cos 2x + 30 \cos 3x$;
   $-30 \sin x - 60 \sin 2x - 90 \sin 3x$;
   $-30 \cos x - 120 \sin 2x - 270 \cos 3x$.

   iv. $\epsilon^{ax}(a \sin bx + b \cos bx)$;
   $\epsilon^{ax}\{(a^2 - b^2)\sin bx + 2ab \cos bx\}$;
   $\epsilon^{ax}\{(a^3 - 3ab^2)\sin bx + (3a^2b - b^3)\cos bx\}$.

   v. $a^x \log_e a$; $a^x(\log_e a)^2$; $a^x(\log_e a)^3$.

   vi. $a^x\{\log_e a \log_e(\sin x) + \cot x\}$;
   $a^x \log_e a\{\log_e a \log_e(\sin x) + 2\cot x - \mathrm{cosec}^2 x\}$;
   $a^x \log_e a\{(\log_e a)^2 \log_e(\sin x) + 3\log_e a \cot x - 2\,\mathrm{cosec}^2 x + 2\,\mathrm{cosec}^2 x \cot x\}$.

2. $Q = 10\epsilon^{-t/cR}$.

3. $i = 10 \sin 5mt$.

4. i. $2ax + by$; $bx + 2cy$; $2a$; $2c$; b ; b.

   ii. $\epsilon^{ax+by}(a \sin xy + y \cos xy)$;
   $\epsilon^{ax+by}(b \sin xy + x \cos xy)$;
   $\epsilon^{ax+by}\{(a^2 - y^2)\sin xy + 2ay \cos xy\}$;
   $\epsilon^{ax+by}\{(b^2 - x^2)\sin xy + 2bx \cos xy\}$;
   $\epsilon^{ax+by}\{(ab - xy)\sin xy + (1 + ax + by)\cos xy\}$;
   the same.

5. i. Max. when $x = 1$ and min. when $x = -1$;
   ii. the same.

H.T. Filter Circuits for D.C. Mains*

By J. H. Owen Harries.

Introduction.

ABOUT two years ago the writer wished to employ in his business receivers capable of deriving their H.T. supply from D.C. electric mains. He tried many of the " battery eliminators " then on the market, but without any success. They worked on some mains and in some houses, but failed to operate at all well in other instances. In consequence it was decided to thoroughly examine the whole subject, and, after some time, a satisfactory instrument was evolved.

The data obtained and its application to design is the subject of this article.

1. Nature of " Ripple."

It is frequently stated that the A.C. ripple superimposed on the D.C. voltage from public mains is caused by the passing of the bars of the commutator of the generating machine under the brushes. Then, obviously, the frequency of the ripple must equal the R.P.S. of the generator multiplied by the number of bars in the commutator. A consideration of a modern large generator will show that this must equal about 1,000 cycles at least, which is a treble note on the piano. But tests on a "bad" main, such as the writer's local one on the East Coast, showed that by far the loudest interference was a hum of about 50 cycles or so, in addition to a general " mush " of other frequencies.

This can easily be accounted for by assuming an unevenness of the generator's output occurring once per revolution and from such causes as a worn or damaged commutator bar, or irregularities in the field flux. Other irregularities would cause other frequencies, and, indeed, may be the cause of the radio frequency " mush " observed by many others as well as by the writer. The frequencies would also heterodyne each other. Then, too, the ripples of the other generators and motors on the line all have their effects.

As will be obvious from this (and as has been shown to be the case by experiment) no two mains (or even different parts of the same main) have ever the same frequencies (or wave-form) of ripple.

It follows, then, that to filter an H.T. supply from these mains by means of an instrument required to work on all supplies equally satisfactorily, one cannot employ a " band " filter of any sort, but must endeavour to produce one having a good efficiency from at least 50 cycles upwards.

2. A Fallacy.

Before proceeding to the actual filter circuits, a common misapprehension must be mentioned. In descriptions of wireless sets (in popular handbooks in particular) it is frequently stated that the impedance of $1\mu F$ and $2\mu F$ condensers are " negligible " at audio frequencies. This might, perhaps, be stated in connection with the old types of L.F. amplifier whose efficiency fell off so very badly at the lower notes, but is certainly incorrect with modern receivers, in many positions in their circuits. In explanation, at the frequency of 50 cycles a $1\mu F$ condenser has a reactance of about 3,330 ohms, and a $2\mu F$ has 1,660 ohms.

As will be shown, this has a considerable effect on H.T. eliminator practice.

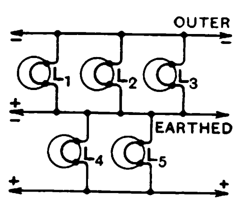


Fig. 1.

Three-wire distribution.
$L_1 L_2 L_3 L_4 L_5$ = *Lamps.*

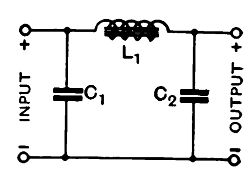


Fig. 2.

First circuit tested.
$C_1 = 2\mu F$. $C_2 = 2\mu F$.
L_1 = *about 70 henries.*

3. Supply Main Connections.

" Three-wire distribution " is usually employed. This is shown in Fig. 1, the lamps representing the method of tapping houses off each outer.

* Received by the Editor, February, 1927.

4. First Circuit Tried.

The investigations were commenced by testing the frequently published circuit of Fig. 2.

This was tried in the laboratory, which has the negative lead of the mains earthed.

Very little "hum" was found to pass, and the writer must admit that he thought that the problem was solved.

5. Effect of Supply with Positive of Mains Earthed.

Further tests in other houses, however, undeceived him. It was found that the trouble was always experienced where the positive of the mains was earthed.

A consideration of Fig. 3 will show the reason.

This diagram shows the circuit of Fig. 2 in use on a positively earthed main with a wireless set. The latter is earthed at E_2 (through C_3 to prevent the mains short-circuiting). The mains are earthed at E_1 (by the electric light company, under Board of Trade regulations).

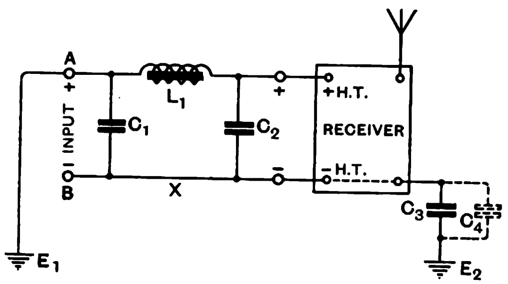


Fig. 3. *Filter in use on positively earthed mains.*
$C_3 = 1\mu F$. E_1=*Company's earth.* E_2=*wireless earth.* C_4=*stray capacities to earth. Other values as in Fig. 2.*

Assume for the moment that the path of the ripple current through L_1 and C_2 is of infinitely high impedance. Then the ripple E.M.F. across AB will cause an A.C. current to flow from E_1 through C_3 and the wireless set back to B, setting up P.D.s across C_3. Since all apparatus in the set may be considered to have a capacity to earth (represented by C_4) in parallel with C_3, these "ripple P.D.s" will be amplified by the valves and so interfere with the signals being received.

As mentioned in Section 2, the usual value of the impedance of C_3 is by no means negligible. C_4 is so small as to have a negligible effect.

To reduce the P.D.s across C_3 and C_4 to the minimum, we can place a very high impedance at X in the path of the stray current. A large inductance may be employed, and will incidentally increase the normal efficiency of the filter as well. This will be further referred to later.

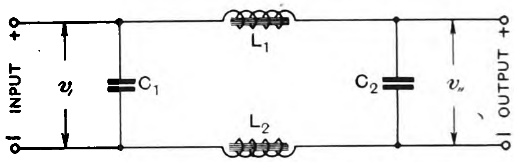


Fig. 4. *Basic filter circuit.*
L_2=*extra inductance.* $v_{,}$=*ripple volts at input.* $v_{,,}$=*ripple volts at output.*

This final arrangement is the basis of the circuit which is in use very successfully to-day. Fig. 4 gives it in essentials.

6. Determination of Practical Values of Circuit Constants.

Referring to Fig. 4, the efficiency of the filter is dependent, obviously, on the percentage $v_{,,}/v_{,} \times 100$ where,

$v_{,}$=the ripple volts across the input,

$v_{,,}$=the ripple volts at the output.

This ratio depends on the relative impedances of the chokes and condensers in the filter, and since none of these quantities can be made either infinitely large or infinitely small, the percentage (which we will call m_1) can never equal zero.

Therefore the designer must take as his object the reduction of m_1 to such a value that $v_{,,}$ has a negligible effect on the wireless set in use.

He may also design for efficient results at about 50 cycles only, knowing that the efficiency must rise with frequency in the case of the filter given (since the reactance of an inductance varies as the frequency, and that of a condenser inversely). In the writer's experience, 50 cycles seems low enough to work to, but, of course, this may vary with the purpose in hand.

The critical value of m_1 mentioned above varies enormously with different receivers, so it was decided to commence a stringent series of tests to determine the correct

values of the several impedances respectively from which m_1 could be calculated, thus obtaining data for future use.

A type of receiver known to be very sensitive to interference from the mains was chosen, and tests were performed on different mains and many different houses on them.

The receiver principally used was an O-V-2 transformer-coupled set. The L.F. valve's H.T. was direct off the filter, and the leaky-grid detector was given about 40v. through a resistance. (See Section 8.) Many other sets were also tried.

After some time satisfactory values for the chokes and condensers were found.

The actual chokes used for L_1 and L_2 (Fig. 4) could be L.F. transformers with primary and secondary in series, or any good choke having sufficient inductance. The values of the latter given in Fig. 5 are the lowest possible for satisfactory operation. Larger ones can always be used.

When these tests were made many of the high inductance chokes now on the market were not yet manufactured, and the writer used those made by Messrs. A. J. Stevens, of Wolverhampton, quite successfully. Also Messrs. Burndept's transformers acted well. These names are mentioned as a guide, as it is often difficult, even nowadays, to obtain an L.F. choke of given inductance. Makers, for some obscure reason, seldom seem to know the figure for their own products.

7. Value of C_1.

It was not found advisable to employ a higher value of C_1 (Fig. 4) than 1μF. There was no increase in the filtering action noticeable by altering it, and at 2μF surges of current were heavy enough to blow 3.5 volt torch bulbs in circuit as fuses. Incidentally, these surges were interesting as they seldom seemed to occur, except on certain parts of the main, and generally coincided with a breakdown of the cables, a by no means very unusual occurrence on some country supplies.

8. Output of Filter.

It is well known that the impedance of the source of common H.T. to an amplifier must be of low value, or a reaction effect may be produced and oscillations commence.

Therefore, a mains filter unit must have an output impedance which is low also, and a condenser (C_2 in Fig. 4) is shunted across it.

Calling this output impedance Z_0

$$\frac{1}{Z_0}=\frac{1}{Z_1}+\frac{1}{Z_2}$$

Where Z_1=the impedance of C_2

Z_2=the impedance of L_1 L_2 and C_1 in series.

The value of Z_2 is very high compared to Z_1 (about 120,000 ohms) and so may be neglected.

Then $Z_0=Z_1$=about 1,660 ohms at 50 cycles with $C_2=2\mu$F.

With more than two efficient stages of L.F. amplification this impedance was found to cause violent oscillation. Fortunately, this may be easily stopped by introducing a resistance into the anode circuit of the further valves. Since these usually do not require as high an H.T. voltage as the last two, the D.C. volt drop on this is immaterial. The resistance is shunted by a 2μF condenser, as shown in Fig. 5, to keep the impedance low here also.

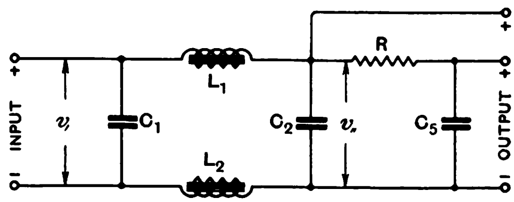


Fig. 5. *Filter for multi-stage amplifier.* C_2 *and* $C_5=2\mu F$ *each.* $C_1=1\mu F$. L_1 *and* L_2= 200 *henries each.* R=50,000 *to* 500,000 *ohms usually.* v, *and* v_o= *as before.* *D.C. resistance of chokes = about 2,000 ohms each.*

The oscillations seem not to be confined to the set itself, but to occur in the oscillatory circuit formed by the chokes and condensers of the filter. As might be expected, the introduction of a low resistance, such as a lamp, across the filter damps the circuit, and so reduces its tendency to oscillation.

9. The Final Circuit.

This is shown in Fig. 5, and the values of the inductance and capacities given.

Referring back to Section 6, we can now proceed to calculate m_1 from the data summarised in Fig. 5.

10. Equation for Value of m_1.

Now, $m_1 = \frac{v_{\prime\prime}}{v_{\prime}} \times 100$ as previously explained, and the object of the filter is to reduce this percentage as much as possible. Let us redraw Fig. 5, as in Fig. 6.

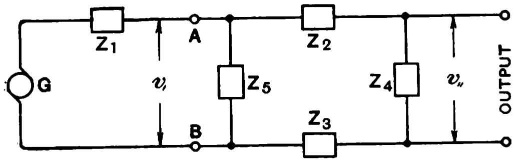


Fig. 6. *Circuit for Fig. 5 redrawn.*

G=generator at power station. Z_1=line impedance of mains. Z_5=impedance of C_1. Z_2=impedance of L_1. Z_3=impedance of L_2. Z_4=impedance of load and in C_2 in parallel. AB=input terminals of filter. $v_{\prime}$=input ripple volts. $v_{\prime\prime}$=output ripple volts, as before.

In the first place, the magnitude of $v_{\prime}$ is proportional to $Z_1 + Z_0/Z_0$ where Z_0 = the input impedance of the whole filter.

Now :—

$$\frac{1}{Z_0} = \frac{1}{Z_5} + \frac{1}{(Z_2 + Z_3 + Z_4)}$$

but $Z_2+Z_3+Z_4$ is large compared to Z_5 and so may be neglected.

Then $Z_0 = Z_5$ for practical purposes.

From this, one would expect that the lower the value of Z_5 (equals the larger the capacity of C_1) the lower the value of $v_{\prime}$ and therefore the higher the efficiency of the filter, provided always that Z_1 has an appreciably high value.

Experiment, however, has shown that it makes practically no difference (to the low frequency ripple anyway) in most cases; the inference being that Z_1 is small compared

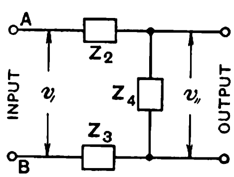


Fig. 7.

with Z_5. In any case the former is bound to vary very greatly in practice, and so it seems wisest to base our design on the worst possible case where Z_1 is negligible.

Then Z_5 will make no difference to the value of $v_{\prime}$ and may be neglected in the calculations. Its value is settled, however, by the reasons given in Section 7.

This then leaves us with the filter circuit of Fig. 7.

Here obviously :—

$$m_1 = \frac{Z_4}{Z_2 + Z_3 + Z_4} \times 100 \quad \ldots \quad (1)$$

11. Equation for Stray Currents.

The effect, already mentioned in Section 5, must also be taken into account, as (1) gives no data for the relative size of Z_3.

We may neglect Z_5 for the reason given in Section 10 and the circuit of Fig. 4 may be redrawn for this calculation as in Fig. 8.

The impedance of the stray capacities of the wireless set to earth are negligible compared to that of C_3. (See Section 5.)

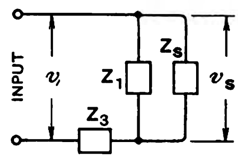


Fig. 8. *Simplified circuit of Fig. 4.*

Z_3=impedance of L_2 (in Fig. 4). Z_1=L_1 and C_2 in series (Fig. 4). Z_S=impedance of wireless earth lead blocking condenser (Fig. 3, C_3). v_S=stray volts across it. $v_{\prime}$=input ripple volts, as before.

Now the efficiency of the filter as regards the stray ripple is proportional to m_2 where

$$m_2 = \frac{v_S}{v_{\prime}} \times 100$$

Therefore from Fig. 8 we can see that :—

$$m_2 = \frac{Z_{S2}}{Z_{S2} + Z_3} \times 100 \quad \ldots \quad (2)$$

where

$$\frac{1}{Z_{S2}} = \frac{1}{Z_S} + \frac{1}{Z_1} \quad \ldots \quad (3)$$

12. Calculation of m_1 and m_2.

If we find, from (1) and (2) (the various "Z" values are, of course, to be added vectorally) the values of m_1 and m_2 for the stringently tested filter of Fig. 5, these will serve as a useful basis of comparison for design in the future.

Since the value of the load resistance will vary considerably in different instances,

and the inductance of the chokes will not be quite constant, there will be no object in working to more than "slide rule" accuracy. Then the figures for Fig. 5 will be as follows:—

$$m_1 = 1.4 \text{ per cent.}$$
$$m_2 = 6 \text{ per cent.}$$

The detailed calculations are given in the appendix.

13. Use of Only One Choke.

In view of these conclusions, the stray current difficulty on positively earthed mains might be expected to be overcome by putting the choke (where only one is in use, Fig. 2) in the minus lead at X in this figure.

Since the writer found this out, he discovered that an eliminator just marketed by a very well-known firm employs this method, but, of course, it suffers from the disadvantage of necessitating a change back to the more usual connections when the mains are negatively earthed.

Further, the method used by the author increases the value of the denominator of the equation (1) as well, and guards against the fact that the "earthed" main is sometimes at a distinct potential above the ground.

14. Case where Set is not Earthed.

Here Z_s (and therefore m_2) will be very large and a hum will usually occur on positively earthed mains.

15. General Considerations.

No trouble has been found by the writer due to saturation of the iron cores of the chokes used, though as much as 20 milliamps or more were passed through them at times.

When using a frame aerial receiver, such as a superheterodyne, the directional effect of the loop aerial is often lost due to the earthing effect (as regards H.F. currents) of the mains unit.

This trouble may be overcome by placing an H.F. choke in each lead from the filter. Over the wavelength band from 200 to 3,000 metres any good commercial chokes have been found satisfactory.

Care should be taken when testing a receiver off a mains unit that any hum noticed is not induced direct into the receiver circuits from the house wiring. Obviously under these conditions, the efficiency or otherwise of the filter will have no effect on the interference. If lead sheathed cables (with the sheaths earthed) are used in the house wiring, no trouble is, as a rule, experienced.

Care also should be taken that the field of the chokes in the filter does not induce the hum in the same way. For this reason the unit should not stand too close to any transformers, etc., in the receiver.

In connection with the design of the chokes to a given inductance, there is some useful data in *E.W. & W.E.*, Vol. 1, page 153.

16. Filters for Giving both H.T. and L.T. Supplies.

If the dimensions and cost of chokes to carry up to one, to one and a half amperes required by the L.T. circuits of most modern loud-speaker sets are calculated (remembering that in addition to avoiding saturation of the core, the ohmic resistance must be correct for the circuit), it will be found that both are so large as to make the filter scarcely a practical commercial proposition.

Of course, one may get round the difficulty by means of using the valve filaments in series, and by using the .06 amp type, but such makeshifts have several disadvantages.

As far as is known at the present time, there is only one make of eliminator to give 1 to $1\frac{1}{2}$ amps or so at 6 volts from D.C. mains, on the market. Its cost of about £60 puts it beyond the reach of most people.

In conclusion, the writer would like to forestall a probable avalanche of letters to the effect that very many people obtain perfect results with the simplest of apparatus—so simple, indeed, as to be scarcely worthy of the name of a filter at all. To these he would reply that he only wishes all supply mains were as amenable as theirs. This unfortunately is not the case!

APPENDIX.

Calculation of m_1 for Fig. 5.

Neglecting the D.C. resistance of the chokes as its effect is negligible, we have:—

$$\omega = 2\pi f = 6.18 \times 50$$
$$Z_2 = L_1\omega j = 60{,}000j$$
$$Z_3 = L_2\omega j = 60{,}000j$$

Taking the resistance of the load as 10,000 ohms, we have :—

$$\frac{1}{Z_4} = \sqrt{\left(\frac{1}{10,000}\right)^2 + \left(-C_2\omega j\right)^2}$$

$$= \frac{1}{Z_4} = \sqrt{\left(\frac{1}{10,000}\right)^2 - .0006j^2}$$

$$Z_4 = -1,650j \text{ ohms about.}$$

Equation (1) is :—

$$m_1 = \frac{Z_4}{Z_2+Z_3+Z_4} \times 100$$

Substituting

$$m_1 = \frac{-1,650j}{60,000j + 60,000j - 1,650j} \times 100$$

neglecting j

$$m_1 = \frac{-165,000}{120,000-1,650} \text{ per cent.}$$

$$= 1.4\ \%$$

Calculation of m_2.

From Fig. 5 we have :—

$$Z_1 = L_1\omega j - \frac{j}{C_2\omega}$$

$$= 60,000j - 1,660j$$

$$= 58,340j$$

Then from equation (3)

$$\frac{1}{Z_{S_2}} = \frac{1}{Z_1} + \frac{1}{Z_S}$$

$$\frac{1}{Z_{S_2}} = \frac{1}{58,340j} + \frac{1}{-3,330j}$$

$$\frac{1}{Z_{S_2}} = .0000171j - .0003j$$

$$Z_{S_2} = -3,400j$$

(We may notice, in passing, that if the circuit Z_1Z_s resonates to a ripple frequency, Z_{S2}—and in consequence m_2—would become very large at this frequency.)

From equation (2)

$$m_2 = \frac{Z_{S2}}{Z_{S2} + Z_3} \times 100$$

Substituting

$$m_2 = \frac{-3,400j}{60,000j - 3,400j} \times 100$$

neglecting j

$$m_2 = \frac{3,400}{566}$$

$$= 6 \text{ per cent.}$$

The load across C_2 and the resistance of the chokes has been neglected, as in the case under consideration their effect is negligible compared with the experimental errors.

Students who wish to work these out for other filters are referred to Captain P. P. Eckersley in *E.W. & W.E.* for January, 1924, and the letter from H. J. Barton-Chapple in February, 1924, in the same journal, for particulars of A.C. calculations.

The Shielded Plate Valve as a High-Frequency Amplifier.

By R. T. Beatty, M.A., B.E., D.Sc.

THE direct amplification of high frequency currents by the use of three-electrode valves presents great difficulties on account of the instability of multi-stage circuits and the small amplification obtainable per stage. These undesirable results are, as is well known, due to capacity currents fed back from the output to the input side through the capacity which exists between the grid and plate of the valve. If this capacity could be reduced to zero, perfect stability could be obtained in multi-stage amplifiers at all frequencies, and the voltage amplification per stage could be raised to a high value by the use of tuned plate circuits of low decrement. Although this ideal has not yet been reached, valves can now be obtained by the public in which the capacity between the electrodes has been reduced to such a low value as to promise a new era in the art of high frequency reception, and in view of the great interest of the subject to all wireless amateurs, the present account of the properties and uses of such valves has been written.

1. Properties of a Valve with completely Shielded Plate.

In such a valve, a fourth electrode or shield, made of wire gauze, is employed and envelops the plate as completely as possible, so that the lines of electric force which in a three-electrode valve run from the plate to the grid, are now intercepted by the shield (Fig. 1). The shield is kept at a fixed positive potential. Since these lines do not pass out through the shield, no effect can be produced on the grid by variations in plate potential: in other words, the plate-grid capacity is zero, and no current can be fed back from the plate to the grid: the valve is a truly unidirectional device.

Strictly speaking, since the shield must be perforated to allow electrons which start from the filament to reach the plate, *some* lines of force which start from the plate must pass through the shield and reach the grid, giving rise to a small residual plate-grid capacity. It will be worth while, however, to assume for the moment that it has been possible to make the shielding complete so that we may realise the results which would be obtained under such ideal conditions. We will also assume that the plate and shield are constructed of a material which does not emit secondary electrons when bombarded by the electrons from the filament; that is that they simply absorb any electrons which reach them. Afterwards, in Section 4, we

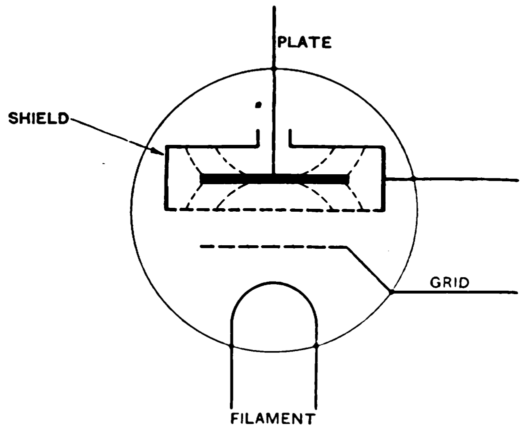


Fig. 1.

will take into account the minute capacity which, unfortunately, cannot be eliminated owing to the exigencies of manufacture, and also see how the behaviour of the valve is modified by the production of secondary electrons.

With these two assumptions in mind we may now consider the flow of electrons from filament to shield under the action of a fixed difference of potential between these two electrodes. A fraction of these electrons will pass through the openings in the shield and be caught by the plate *whatever its potential may be*, provided only that the lowest value of its potential is a few volts above that of the filament. If I_p be the

plate current and V_p the plate potential, it follows that $d\,I_p/d\,V_p = 0$, and the differential resistance (or internal resistance), which is the reciprocal of this quantity, is infinite.

The properties of the valve may accordingly be summed up by the two equations,

$$C_{pg} = 0 \quad \ldots \quad \ldots \quad (1)$$

$$R_v = \infty \quad \ldots \quad \ldots \quad (2)$$

where C_{pg} is the plate-grid capacity and R_v is the differential resistance of the valve.

2. Valve Specified by a Single Characteristic Curve.

If we make the usual proviso that sufficient grid bias is applied to keep the grid current zero, then since R_v is infinite, the only numerical constant relating to amplification which the valve possesses is its mutual conductance g. That is, when the shield is kept at a suitable positive potential and the relation is plotted between grid volts and plate current, the potential of the plate being immaterial provided only that it is at least a few volts above that of the filament, the resultant curve specifies the valve completely as regards the variation in plate current to be obtained by varying the grid potential. In the case of a three-electrode valve as we vary the voltage applied to the plate from one valve to another in steps we obtain a set of characteristic curves, but as mentioned above in the case of a shielded plate valve, variations of plate voltage are without effect and consequently the usual set of curves is replaced by a single characteristic. If the instantaneous values of the plate current and grid voltage be I_p and V_g then

$$d\,I_p/d\,V_g = g \quad \ldots \quad \ldots \quad (3)$$

and g, the mutual conductance, is the slope of the characteristic curve.

If we limit ourselves to the straight portion of the characteristic and apply an alternating E.M.F. of instantaneous value v_g to the grid, then the resulting alternating plate current has the instantaneous value i_p given by

$$i_p = g\,.\,v_g \quad \ldots \quad \ldots \quad (4)$$

3. Voltage Amplification.

If a resistive load of magnitude R ohms be inserted in series with the plate, the potential drop across it due to v_g is $v_p = Ri_p$: substituting for i_p from e_q (4) we get

$$v_p = R \cdot g \cdot v_g \quad \ldots \quad \ldots \quad (5)$$

and the voltage amplification m is given by

$$m = v_p/v_g = R \cdot g \quad \ldots \quad (6)$$

and is limited only by the maximum value of R which can be obtained. The resistive load may be formed by a tuned plate circuit (Fig. 2) with large coil and small condenser.

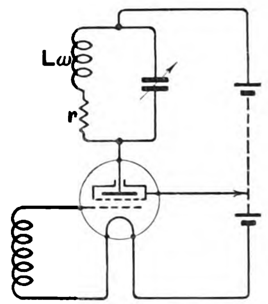


Fig. 2.

The largest values of equivalent resistance $L^2\omega^2/r$ of such rejector circuits which can be ordinarily obtained in amplifier circuits, are given in column 2 of the subjoined table and the corresponding values of m are given in column 3, assuming a mutual conductance of 0.4 milliamp per volt.

TABLE I.

$g = 0.4$mA/volt. $R_v = \infty$

Frequency kilocycles	$R = L^2\omega^2/r$ ohms	$M = R \cdot g$
100	4×10^5	200
1,000	10^5	40
10,000	10^4	4

These calculated values for single stage amplification are truly remarkable. Let us now investigate the experimental results: It will be shown below that with actual apparatus, including commercial valves and valve components and with quite simple circuits, amplifiers can be built in which the amplification per stage approaches the values given in Table I, and in which perfect stability is assured at all frequencies.

4. Hull's Shielded Plate Valve.

In deducing equations (1) and (2) two assumptions have been made (*a*) that the plate is completely shielded, (*b*) that no secondary electrons are emitted from the plate or the shield. An experimental type of valve constructed by Hull* at Schenectady almost fulfils the first condition as is shown by Curve 1, Fig. 3, in which the sum of plate and shield currents is plotted against plate voltage: the line is practically horizontal showing that the flow of electrons from filament to grid is affected only to a minute

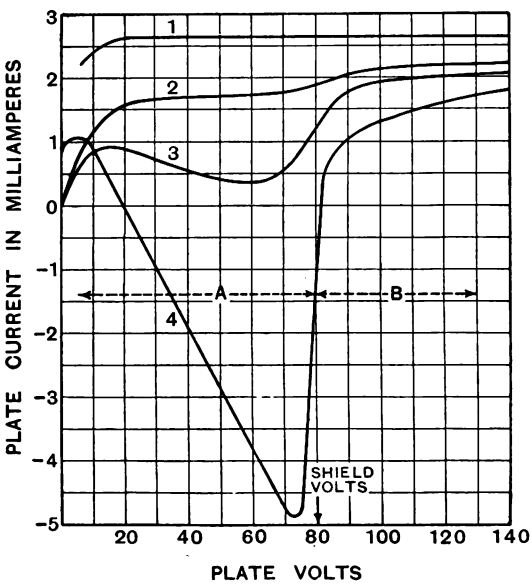


Fig. 3.

extent by the potential of the plate and consequently that very few lines of force reach from plate to grid. This result was achieved by making the shield of thin plates placed edge on to the incoming electrons like an open Venetian blind (Fig. 5). When plate current is plotted against plate volts with 80 volts (marked by an arrow) on the shield and with polished nickel electrodes Curve 3, Fig. 3 is obtained. The region *A* shows a negative characteristic due to emission of secondary electrons from the plate: as the plate potential is increased the primary electrons move faster and set free more secondary electrons from the plate so that the plate current diminishes. When the plate potential exceeds 80 volts

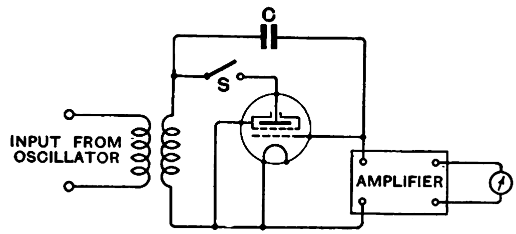


Fig. 4.

the secondary electrons are pulled back to the plate and the negative characteristic disappears: the positive slope in region (*B*) is due to the cloud of secondary electrons surrounding the shield of which more and more are pulled to the plate, as the plate potential is increased. These statements are verified by an experiment in which plate and screen were coated with colloidal nickel black which acts as a trap for the secondary electrons: as Curve 2 shows the negative characteristic disappears, and all lines become more nearly horizontal. The other extreme is shown in Curve 4 where the slopes have been accentuated by coating the electrodes with a layer of high secondary emission: these negative characteristics are, of course, familiar in the case of the dynatron invented by Hull many years ago.

On the right of the 80-volt ordinate the curves become straight in the vicinity of 130 volts and the differential resistances given by Curves 2, 3, 4, are respectively 7×10^5, 5×10^5, 10^5 ohms.

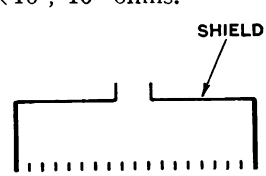


Fig. 5.

The residual plate-grid capacity was measured in the following way (Fig. 4). An oscillator was inductively connected to the plate of the valve, the shield being directly connected to the cold filament. The signal produced in this way was transmitted to an

* Hull and Williams, *Physical Review*, 27, 4, April, 1926, p. 432. The curves in Fig. 3 are substantially those given in this paper.

amplifier and detector partly through the plate-grid capacity and partly through a very small condenser C composed of a cylinder of inner diameter 2.5 mm. with a thin wire (.125 mm. diameter) along the axis. The reading of the milliammeter in series with the plate of the detector was noted and then by means of the switch S the valve was cut out and the reading brought to the same value as before by sliding the wire of the condenser C farther into its surrounding cylinder. In this way the value of the plate-grid capacity could be calculated *and it worked out at the very small value of* $0.006\mu\mu F$. This remarkably low value should be compared with the ordinary values for three-electrode valves which vary between 2 and $50\mu\mu$F.

shown in Fig. 2: we get the well-known expression

$$\frac{mR \cdot g}{1 + (R/R_v)} \quad \ldots \quad \ldots \quad (9)$$

At frequencies of and above 1,000 kilocycles the ratio R/R_v may be neglected in comparison with unity: at lower frequencies m will be appreciably smaller than its value for a valve whose differential resistance is infinite since at such frequencies R can be built up to values comparable with R_v as is evident from Table I.

On measuring the amplification actually produced in a circuit arranged as in Fig. 2 with a signal applied between the grid and the filament, Hull found values at 1,000 and 10,000 kilocycles agreeing with those calculated in Table I, and by using a special low loss coil at 10,000 kilocycles composed of a self-supporting spiral of copper tube the figure for m was raised from 4 to 7. He also showed that by careful screening a four-stage cascade amplifier could be built up using in each stage a tuned plate system connected to the following grid through a condenser and grid-leak, the total amplification for four stages being a million at 1,000 kilocycles. No sign of instability or regenerative action was noticed; this being due to the extremely small value of the internal feed-back.

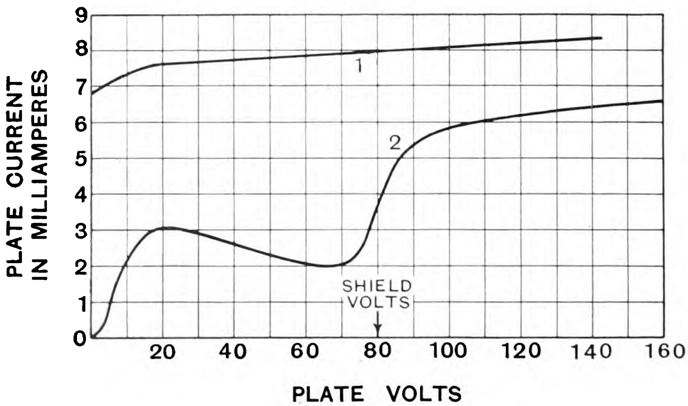


Fig. 6.

Equations (1) and (2), which are only true for a theoretically perfect valve, now become

$$C_{pg} = 0.006\mu\mu\text{F} \quad \ldots \quad (7)$$
$$R_v = 5 \times 10^5 \text{ ohms} \quad \ldots \quad (8)$$

and a proviso must be made that the potential of the plate be kept above that of the shield, otherwise R_v will fall to a low or even a negative value on account of the presence of secondary electrons emitted by the plate and shield. If it were not for these secondaries the plate swing could be extended to within a few volts of the filament potential as mentioned in Section 2.

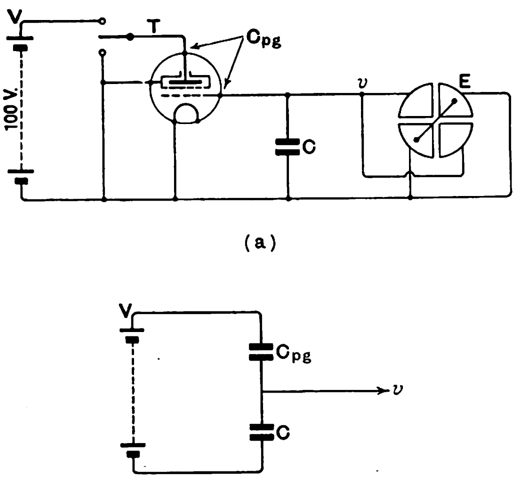
Since R_v is not infinite in this valve the expression for the voltage amplification given in *eq* (6) must be modified to allow for the shunting effect of the plate resistance on the resistance of the plate rejector circuit

Such results are impressive, but as this particular valve has not so far emerged from the laboratory stage, we will not dwell on it further but will consider a type which is now available to the wireless amateur.

5. Commercial Shielded Plate Valve.

(A) *General Characteristics.*

Shielded plate valves can now be obtained in which a compromise has been made between the complications requisite for almost perfect shielding and the simplicity necessary for manufacture. The valves are double ended, the filament and grid leads being at one end, the plate and shield at the other. The shield is a disc of coarse wire gauze lying between the disc-shaped plate and the grid. Fig. 6 (1) gives the relation between plate volts and total current to plate and shield, the grid being connected to the negative end of the filament, and the shield being kept at 80 volts. The slope of this curve is greater than in Hull's valve, the reason being that the coarse shield does not screen the plate so effectively, so that an increase in plate potential causes more electrons to be pulled through the grid. Curve (2) shows the plate current only, the differential resistance R_v which is obtained from the slope of this curve is 1.25×10^5 ohms in the vicinity of $V_p=150$ volts. The mutual conductance is 0.8mA/volt, this high value being due to the open mesh of the shield.



(a)

(b)

Fig. 7.

The plate-grid capacity was determined in the following simple way, (Fig. 7): A potential V of about 100 volts was suddenly applied to the plate through a tapping key T, the shield being earthed and the filament unlighted. The grid was connected to one pair of quadrants of a Lindemann quartz fibre electrometer and a capacity C was placed between grid and filament. Since the arrangement is equivalent to the simplified diagram shown in Fig. 7(b) with C and C_{pg} in series we have

$$(V-v)/v = C/C_{pg}$$

Where v is the potential shown by the electrometer: A variable 50$\mu\mu$F condenser was used for C.

The value thus found for C_{pg} was 0.1$\mu\mu$F: this is much larger than the value 0.006$\mu\mu$F given by Hull's valve but nevertheless is a great improvement on the grid-plate capacities of three-electrode valves.

(B) *Voltage Amplification from Grid to Plate.*

This was measured for the circuit shown in Fig. 8.

The untuned grid circuit was excited by inductive coupling from an H.F. oscillator and the grid voltage measured by a Mouillin voltmeter M. The coil of the tuned plate circuit was of a well-known commercial type in which a single layer coil is screened by a copper pot. The voltage induced across the coil was measured by a cathode-ray oscillograph shunted by a megohm, a 1,000$\mu\mu$F condenser being inserted in the lead from the lower end of the coil. Table II gives the results obtained.

TABLE II.

Frequency kilocycles.	$m = v_p/v_g$
500	58
1,000	36
1,500	30
2,000	23
3,000	17
4,000	13

(C) *Stability of Single Stage Amplifier with Tuned Grid and Tuned Plate Circuits.*

The circuit shown in Fig. 8 is stable since a low resistance input is used; if, however, this is replaced by a tuned grid circuit, as in Fig. 9, instability is possible and it is of great interest to see how low the decrements of the two circuits can be made before oscillations set in.

It can be shown, though the proof* is too long to insert here, that the amplifier shown in Fig. 9 will be stable provided that H is less than 2, where

$$H = \frac{C_{pg}\omega . g}{\frac{r_1}{L_1^2\omega^2}\left(\frac{r_2}{L_2^2\omega^2} + \frac{1}{R_v}\right)} \quad \ldots \quad (10)$$

The amplification may be divided into two parts :—

1. The amplification from grid to plate; 2. The amplification produced by the tuned-grid circuit on a signal injected into the grid coil from an untuned coupling coil in series with the aerial, and these amplifications are

(*a*) m_2 (from grid to plate) $= \frac{g}{\frac{r_2}{L_2^2\omega^2} + \frac{1}{R_v}}$ (11)

(*b*) m_1 (due to grid circuit) $\frac{L_1\omega}{r_1}$ ... (12)

and the total amplification is $m_1 m_2 F$ where F is a multiplying factor due to the reaction through the grid plate capacity: equations (11) and (12) are well-known expressions: (11) is identical with (9) given above.

If $H=2$, the amplifier is on the verge of self-oscillation and F is very large, as H decreases F decreases also, and when $H = 0.625$, F has the value 1.2 (these results are proved in the paper referred to above). When $F = 1.2$ the increase in amplification due to internal feed-back is only 20 per cent.

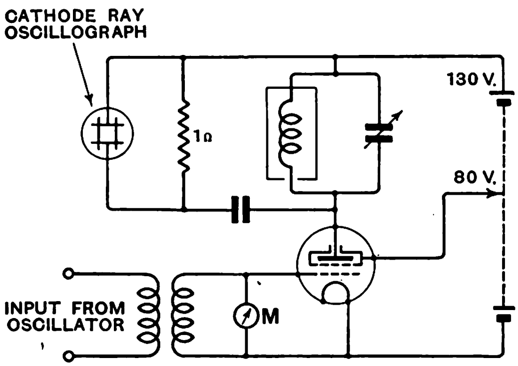


Fig. 8.

and we will call this condition one of negligible reaction.

These results enable us to calculate the largest values of m_2 which can be realised in single-stage amplification before instability sets in. For simplicity we assume that in equation (10) identical coils are used in the grid and anode circuits, that is, that

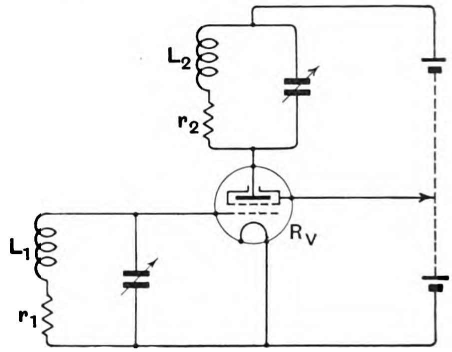


Fig. 9.

$$\frac{r_1}{L_1^2\omega^2} = \frac{r_2}{L_2^2\omega^2}$$

and we then work out the least value which each term can have in the two cases

(1) $H = 2$; (2) $H = 0.625$.

The constants as ascertained in Section 5(A) are—

$$C_{pg} = 0.1\mu\mu\text{F}$$
$$g = 8 \times 10^{-4} \text{ amp/volt.}$$
$$R_v = 1.25 \times 10^5 \text{ ohms} \quad \ldots \quad (13)$$

The results are given in Table III.

The figures in Tables II. and III. are plotted in Fig. 10.

Curve 1 gives the maximum grid-plate amplifications that can be obtained with the amplifier shown in Fig. 9 at the limit of stability. Curve 2 gives the corresponding value when the reaction is negligible. The experimental values with a screened tuned-plate circuit (Fig. 8) given in Table II. are shown in Curve 3.

Curve 3 overshoots the stability limit Curve 1 in the region between 500 and 800 kilocycles: as the frequency is increased the curve drops towards Curve 2 indicating negligible reaction. The variation of tuning of the amplifier over the complete range of 500 to 4,000 kilocycles

* See a forthcoming paper by the writer in the *Philosophical Magazine* on "Resonant Circuits with Reactive Coupling."

was, of course, not carried out with the same plate coil throughout: the region was divided into four ranges and a suitable coil used for each range.

TABLE III.

Theoretical maximum values of voltage amplification from grid to plate:—

1. **At limit of stability when $H = 2$;**
2. **With negligible reaction when $H = 0.625$.**

Frequency kilocycles.	$L_2^2\omega^2/r_2$		m_2	
	$H=2$	$H=0.625$	$H=2$	$H=0.625$
500	1.27×10^5	6.11×10^4	51	33
1,000	8.1×10^4	4.06×10^4	39	25
2,000	5.35×10^4	2.8×10^4	30	19
5,000	3.16×10^4	1.69×10^4	20	12
10,000	2.16×10^4	1.17×10^4	15	8.5

From the coincidence of Curves 1 and 3 in the vicinity of 800 kilocycles, it follows that an amplifier, as shown in Fig. 9, should be on the point of self-oscillation when tuned

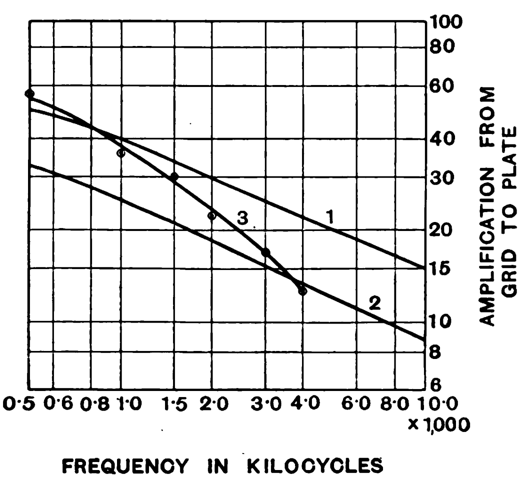


Fig. 10.

near this frequency. It was found actually that using similar screened coils for L_1 and L_2 oscillation could easily be produced by increasing the filament current so as to raise the value of the mutual conductance. The system also became unstable at this frequency by raising the copper screens slightly so as to allow a small amount of induced reaction between the grid and anode coils.

Apart from the screening of the coils, no special precautions were taken with the circuits except that the grid and plate leads were kept well separated: the necessity for this spacing is shown by the following experiment: one end of a short wire was fastened to the plate lead and the other brought within half an inch of the grid lead whereupon the extra plate-grid capacity so produced (a fraction of $1\mu\mu F$) was sufficient to set up self-oscillation.

(D) *Total Voltage Amplification Obtainable.*

We have only considered so far the amplification from grid to plate but this must be multiplied by the corresponding amplification from injected signal to grid to get the total effect. This is the quantity called m_1 in equation (12). m_1 was found experimentally for each of the screened coils used in the grid circuit in Fig. 9 and the results are given in the second column of Table IV.

TABLE IV.

Frequency kilocycles.	m_1	m_2	m_1m_2
500	80	51	4,100
1,000	80	36	2,900
1,500	83	30	2,500
2,000	79	23	1,800
3,000	78	17	1,300
4,000	76	13	990

The third column contains the values of m_2, borrowed from Table II,* and the total amplification, omitting the additional effect due to reaction, appears in the final column. It is unusual to include the effect given by the grid circuit in the expression for the amplification but it is quite justifiable since in designing for stability we must take both the grid and plate circuits into consideration.

The questions of selectivity and of multi-stage amplification raise some extremely interesting points and it is hoped to deal with these in a future paper.

* Except in the case of the first row: the system is unstable at this frequency as will be seen by reference to Fig. 10 and the value 51 for m_2 given by Curve 1 has been used instead of the unstable value 58 given by Curve 3.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

The Performance of Reflexed Valves.

To the Editor, E.W & W.E.

SIR,—May I be allowed to point out two rather unfortunate errors in the otherwise excellent article by Mr. D. Kingsbury in your issue for September ?

In the first place, it is stated that the form of the voltage wave occurring at the terminals of the secondary of the A.F. transformer, is either as in Fig. 3(b) or 3(c), depending, among other things, on the R.F. transformer connections. Reversing the R.F. transformer connections can, however, only have the effect of reversing the phase of the high-frequency input to the rectifier, and it can easily be seen, *e.g.*, by turning Fig. 3(a) upside down, that this has no influence on the phase of the low-frequency output.

Secondly, with reference to Fig. 3(d) and 3(e), Mr. Kingsbury states that in (d) :—

> " the mean of the combined wave (dotted line) is positive in respect to the mean of the basic A.F. and R.F. waves (full line) " ;

and in (e) that :—

> " the mean of the combined wave is negative in respect to the basic waves."

That this is incorrect can be easily demonstrated by redrawing Figs. 3(d) and 3(e) on squared paper, and calculating the areas above and below the thick line. These will be found equal, thus showing, as would be expected, that when the two waves are combined the new mean is the same as the means of the separate waves.

The change in the anode current which was found to result on shorting the transformer secondary, can easily be explained as due to the combined waves overrunning on to the bend of the characteristic, although this need not have been enough to produce noticeable distortion, or even the " reflex interference note."

Dulwich, S.E.21. W. S. PERCIVAL.

To the Editor, E.W. & W.E.

SIR,—I have to thank you for forwarding to me Mr. Percival's letter pointing out certain errors in my article on Reflex Circuits in the September issue.

Needless to say I welcome all such criticism since it brings us nearer complete understanding of these very interesting and, in my opinion, by no means defunct circuits.

I have given Mr. Percival's letter consideration, and there is no doubt that on both counts he is correct.

In regard to his second point, it was the radio-frequency transformer which was shorted when receiving signals and not the audio-frequency transformer as stated in my article. This undoubtedly gives the rise and fall in anode current observed, and but for a further complicating feature I should probably not have misinterpreted the results obtained.

I was at the time using a voltage-doubling type of H.T. supply rectifier which, while having the advantage of supplying comparatively high voltages when only small anode currents are required, has the disadvantage of high apparent internal resistance. (I actually deduced the resistance of this particular rectifier to be some 56,000 ohms.) With liberal capacity across the output terminals of such a rectifier no ill effects are observed under working conditions, but—and this is the complication—any small change in bias or filament temperature produces only a transitory change in current in accordance with the valve characteristics, followed by a very much smaller change in steady current.

I apparently misread the transient rise and fall in anode current as being due to a shift in the mean grid potential of the valve, whereas it was actually due to the cessation of the D.C. component of the crystal output flowing through the audio-frequency transformer primary.

I do not think the main issue of the derivation of the reflex interference note is affected, and since the observed changes in anode current actually helped me to trace the matter out, the coincidence of effects was indeed a fortunate one.

Pulborough, Sussex. D. KINGSBURY.

BOOK REVIEW.

ITALIAN WIRELESS YEAR BOOK AND DIRECTORY, 1927.

The second edition of the *Radio Annuario Italiano*, the only Italian Wireless Directory, contains a mass of information useful alike to the amateur and the trader. A brief review of the progress of radio-telephony and telegraphy in Italy is followed by a summary of the Laws and Regulations passed since 1903 and information concerning tariffs and general statistics. There is a comprehensive list of the commercial and official land stations in Italy and her Colonies and of the broadcasting stations of Europe. The first part concludes with various useful notes on wireless matters, including codes and abbreviations used in morse transmissions, and particulars of the personnel and functions of the Ministry of Communications and other Ministries and Corporations concerned with Wireless Telegraphy and Telephony.

The second section of the book comprises a Directory of Wireless Traders, Manufacturers and Agents. The book is published by *Radio Novita*, Via Porto Maurizio 12, Rome, price 35 lire or 9s. 6d., post free.

The Amplification of Small Currents by means of the Thermo-Relay and the Photo-Electric Cell.

By James Taylor, M.Sc., Ph.D., A.Inst.P.

Introduction.

THE present article describes a method for the magnification of the deflections of a galvanometer mirror as developed at Utrecht by Moll and Burger, for the measurement of extremely small currents. This method of amplification by means of the "thermo-relay"* is not so widely known in England as it deserves to be, and it is hoped that the following description of the method will prove of interest and use to those engaged in precision measurements for wireless research and other purposes. Further, a new and similar method of amplification utilising the properties of the photo-electric cell will be described.

As a rule mirror galvanometers of the suspended coil and suspended magnet type are used for the measurement of very small currents. Electrostatic methods in which an electric charge and a time are measured simultaneously (from which the current which is equal to the charge divided by the time, may be deduced) are also used in some types of work, but are not generally applicable.

Suspended coil instruments are most frequently used because they are preferable from many points of view to the suspended magnet types. In order to make a galvanometer sensible to very small currents it is usual to increase the number of turns of wire upon the moving coil. This has the great disadvantage of increasing the bulk of the moving parts and augmenting the resistance of the galvanometer. The result of increasing the inertia of the coil is to make the galvanometer sluggish in action, that is, to give it a long time period, and for many types of work it is impossible to use a long period instrument. Further, owing to the high resistance of the galvanometer it cannot be used in relatively low resistance circuits, for its introduction would entirely disturb the circuit conditions and most of the electrical energy of the circuit would be absorbed in the galvanometer system itself.

By utilising the thermo-relay method, however, it is possible to equal and surpass the performance of the most sensitive galvanometer whilst retaining a short time period and a comparatively low circuit resistance if required.

The possibilities of these particular methods have been but little explored and it is not impossible that their range of usefulness on the technical side may be considerable.

The thermo-relay is dependent for its efficiency upon certain new types of thermocouples introduced in recent years and largely developed by Moll (see Moll, *Proc. Phys. Soc. Lond.*, xxxv., p. 258, 1923; Moll and Burger, *Phil. Mag.*, Vol. I., Sept., 1925), consequently some preliminary remarks about thermocouples in general, and especially those used for the measurement of radiation are necessary. The subject of thermo-elements is of importance in the technical branches of wireless so that no apology is needed for the introduction of the subject here.

Thermo-elements.

Let us suppose that we have a piece of copper wire AB joined at its ends A and B (see Fig. 1) to iron wires AD and BC respectively and a galvanometer (low resistance) or other current indicator is connected between the ends C and D of the iron wires, there will be no current indicated by the galvanometer DC provided the junctions A and B of the copper and iron wires are

* [Illustrated pamphlets and price lists of these thermo-relays have recently been issued in English by the makers, P. J. Kipp & Sons of Delft.

A short description of the use of the Moll & Burger vacuum thermo-relay for amplifying galvanometer deflections was given by Prof. A. V. Hill in the Journal of Scientific Instruments, Vol. IV, p. 4, October 1926.—ED.]

at the same temperature. If, however, A and B are at different temperatures a current will be indicated by the galvanometer. This is the basal experiment in thermo-electricity which was discovered as long ago as 1821 by Seebeck. In the above described example the current flows from the copper to the iron at the hot junction and from the iron to the copper through the cold junction.

Such a combination of two metals which gives rise to an electromotive force and a current (if the circuit is closed) when there is a difference of temperature between the two metallic junctions, is called a thermocouple or thermo-element. Almost any two metals may be used but some combinations are much more efficient than others. Certain simple experimental laws relative to the behaviour of thermo-elements have been discovered. The greater the temperature difference between the hot and cold junctions (within certain defined limits) the greater is

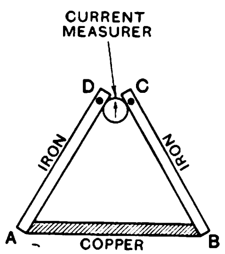


Fig. 1.

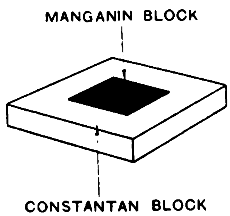


Fig. 2.

the electromotive force generated in the circuit. Thermo-elements may be used in series and a battery is thus formed of which the total electromotive force is equal to the algebraic sum of the electromotive forces of the component elements. We see as a consequence that the ends of a thermocouple may be connected to a galvanometer, or soldered, without interfering with the circuit electromotive force conditions. This result is of experimental importance.

The electromotive forces obtained from thermocouples are small; in the case of the iron copper couple for example with the cold junction at 0°C. and the hot junction at 100°C. the voltage set up in the circuit is only slightly greater than a thousandth of a volt.

Thermocouples have received sundry uses for the measurement of alternating current (employed as current converters) and for the measurement of radiation intensities. Batteries consisting of small rods of antimony and bismuth arranged so that the alternate junctions are all at one side, and blackened, as in the Melloni Thermopile, have been employed for the measurement of infra-red radiation, but the performance is uncertain at best and many difficulties are encountered in use.

The sensitivity of a thermocouple composed of a given pair of metallic components, depends upon the difference of temperature between the two junctions set up by a given cause heating one of the junctions. Thus, if radiation were falling upon one of the junctions, the temperature of this "irradiated" junction would rise indefinitely, in the ideal case where no heat losses are experienced. In practice the case is different. Heat is lost by convection of heat in the surrounding air, by conduction through the metal components, and by radiation.

Originally thermo-elements were always constructed in air, but nowadays they are very frequently mounted in an evacuated vessel so that a considerable increase in the sensitivity and reliability is obtained, due to the diminution in the heat losses to the surrounding air, and the absence of erratic air movements in the vicinity of the couple.

The loss of heat by conduction through the metal components of the element may be decreased by reducing the cross section of the component strips. This entails, however, a concurrent increase in the electrical resistance of the system so that the reduction of the heat conductivity should only be carried down to a certain "optimum" point.

Another point of great importance in connection with a thermo-element is the time required for it to give a reading that can be taken as approximately the equilibrium value. The equilibrium value takes, theoretically of course, an infinite time to be arrived at, but for practical purposes the "quickness" of a thermo-element may be defined as the time required to reach a value 99 per cent. of the real equilibrium value.

The quickness depends upon a variety of circumstances. It is less the greater the heat capacity of the elements which are heated. It is further greatly improved when the element is surrounded by air, for this

brings about a quicker temperature equilibrium of the system. Nevertheless the increase of sensitivity gained by enclosing the element in vacuum more than counterbalances the disadvantage of a somewhat smaller quickness.

Moll and Burger (*loc. cit.*) have constructed thermo-elements fulfilling the required conditions for accurate and quick performance. To this and a special metal foil called

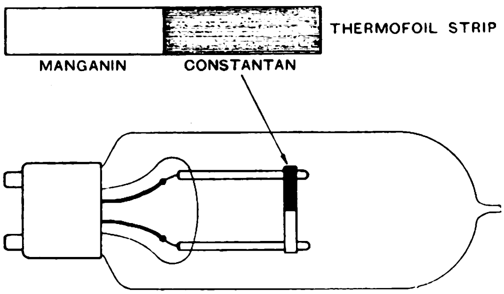


Fig. 3.

thermofoil was first made (see Moll, *loc. cit.*). (Moll's first thermocouple was constructed in 1914.) A rectangular section is cut out from the middle part of a block of constantan (see Fig. 2) and into this section an exactly-fitting block of manganin is silver-soldered in such a manner that a minimum of solder is used. (This method is employed because the composite block so formed is perfectly symmetrical and can be rolled out uniformly much more easily than bars of simpler construction.) The thickness of the bar is reduced by successive rollings until it is of the order of a few microns* (a micron is a thousandth part of a millimetre). Strips of this foil of the required width can be cut out across the section. They are blackened on one side by a varnish of colloidal carbon so that efficient absorption of radiation falling on the strip occurs. The strip is soft-soldered upon the leads of a small lamp-bridge which is then mounted in a glass bulb, and evacuated (see Fig. 3, which shows one type of this kind of thermo-element).

These sort of thermocouples (see Moll and Burger, *loc. cit.*) have a quickness of about 2 or 3 seconds and a resistance of from 10 to 20 ohms.

* The thickness of the thermofoil used for vacuum elements is from 1 to 1.5μ. 0.9μ is the thinnest that has so far been used.

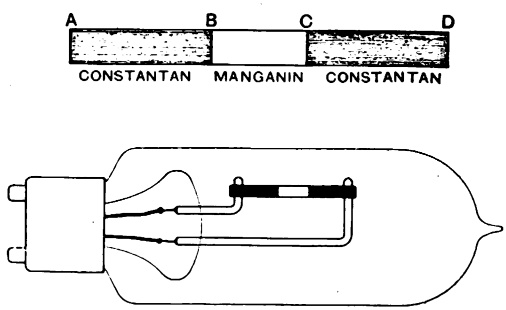
The Thermo-relay.

The thermo-relay is simply a composite thermo-element of the same type. The strip of thermofoil consists of three parts (see Fig. 4), *AB* and *CD* being of constantan and *BC* of manganin. The foil is blackened upon one side and mounted in an evacuated vessel as above described. (Fig. 5 shows a thermo-relay.)

It is easily seen then that the thermo-relay consists of two similar junctions in series, and opposing each other.

In practice the relay is connected in series with a galvanometer which may conveniently be of the suspended-coil mirror type.

If now the image of a source of light is thrown upon the portion *BC* of the strip, there will result—as a rule—a deflection of the galvanometer, indicating that a current, due to the unequal heating of the junctions *B* and *C*, is flowing in the circuit. By adjusting the relay in a direction perpendicular to the direction of the light beam (that is in the direction of the strip) the galvanometer deflection may be reduced to zero. This state is attained when the junctions *B* and *C* are symmetrically heated and the electromotive force from the one is exactly equal and opposite to that from the other. This then is the principle of the method for the magnification of small deflections of a galvanometer mirror.



Figs. 4 and 5.

In practice the method is usually employed in the following manner: The first circuit (see Fig. 6) in which the small current to be measured flows, is connected in series with a suspended coil galvanometer of the Moll type (resistance about 40 ohms). Other types of galvanometer, or a string galvanometer (in which the mirror rotates),

may of course conveniently replace the Moll instrument. Fig. 6 gives a diagrammatic representation of the apparatus. A source of light, for example a half-watt ten-volt lamp, supplied from accumulators so that it maintains a constant intensity, illuminates a rectangular slit mounted upon a convergent lens which converges the transmitted beam upon the mirror of the first galvanometer. The beam is reflected from the galvanometer mirror and is then further length until no deflection of the second galvanometer, which is connected in series, is produced.

If now the mirror of the first galvanometer suffers a deflection due to a small current passing through its coil, a displacement of the beam of reflected light through twice the angle of movement of the galvanometer takes place, the position of the image upon the relay is altered, unsymmetrical heating of the junctions *B* and *C* occurs, and

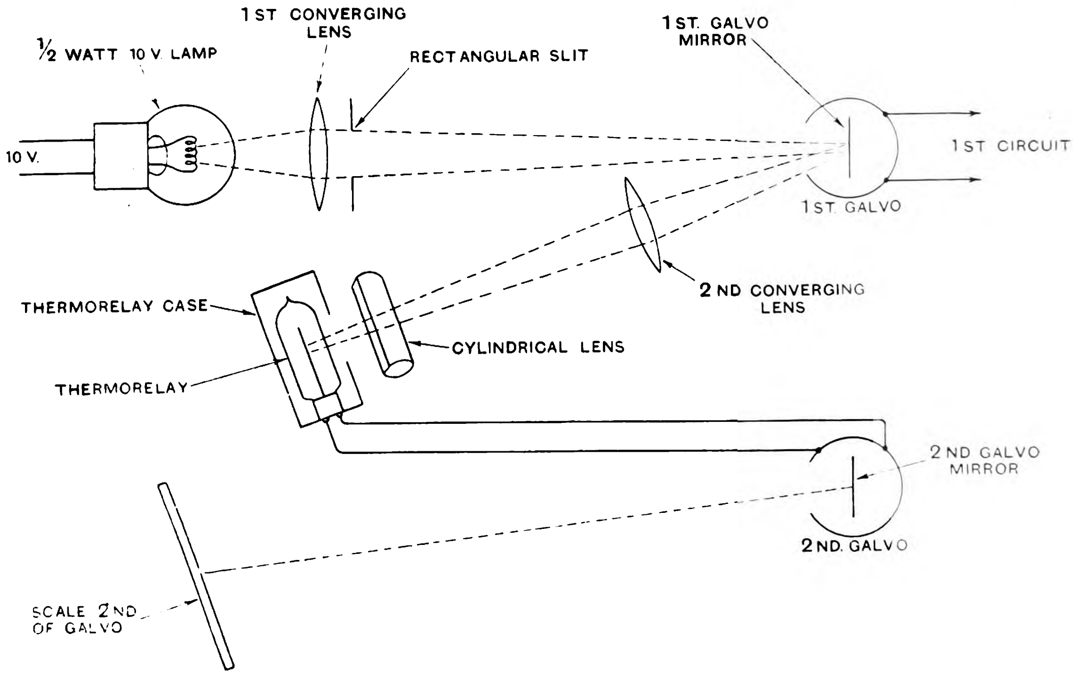


Fig. 6.

concentrated by means of a second converging lens so that it forms an image of the rectangular slit on the thermo-relay strip. By means of a cylindrical lens the image is concentrated to a line of light and adjustment is made so that the linear image of the rectangular slit falls on and along the part *ABCD* of the strip.

It is to be noted that the adjustment is made so that the strip is at the focus for the infra-red radiation which, as is well known, is chiefly effective in producing the heating effect of the junctions. The relay is usually mounted in a case provided with a fine screw lateral movement so that it can be adjusted in the direction of the strip the second galvanometer registers a deflection that is greatly in excess of that of the first galvanometer.

For small rotations of the mirror of the first galvanometer, that is, for cases in which the displacement of the image on the thermorelay strip is not large, the second galvanometer reading is directly proportional to the rotation of the first galvanometer. That is to say, for small currents, the amplification is linear.

Utilising such a method, amplifications of a hundred and in some cases five hundred may be obtained and, owing to the thinness of the relay strip, the time period for response of the instrument is short. Indeed

if an aperiodic galvanometer of small period is employed the final deflection is reached after two and a half or three seconds.

Currents in the first galvanometer circuit of as little as 10^{-11} amperes may produce one mm. deflection of the light spot of the second galvanometer (scale about one and a half metres from the galvanometer). This is not to say, however, that currents of such an order can be accurately measured by the method ; the performance is limited by the Brownian Movement of the coil of the first galvanometer. In recent years the Brownian Movement has been recognised as of first rate importance and has received considerable attention both in its practical and theoretical aspects. As is well known, all particles of matter, whether small beyond the limits of microscopic examination, or large, participate in an erratic and haphazard movement brought about by the universal temperature kinetic energy (energy of motion) of the molecules and atoms of all substances.

Now, the galvanometer coil though of proportions gigantic relative to atoms, to molecules, and to the particles of colloidal solutions, is nevertheless actuated by a Brownian Movement, produced by the perpetual and discontinuous bombardment of the coil by the molecules of the surrounding air, and from other causes.

Ising, and Ornstein (Ising, *Phil. Mag.* 7, 827, 1926. Ornstein, *Zts. of Phys.* 41, 11/12, 848, 1927) have shown that this produces a movement of rotation which although exceedingly minute comes notwithstanding into the range of possible measurement by the present method.

With the Moll galvanometers referred to above, the average rotation of the coil due to the Brownian Movement is of about the same magnitude as that produced by a current of 10^{-11} amperes, consequently on either side of this value the coil is actuated by erratic small changes of position, and measurements of currents of this order have no precise significance.

The higher the resistance of the galvanometer coil the less is the Brownian Movement.

In utilising the method great care must be taken to protect the system from electrostatic charge effects, contact electromotive forces, and extraneous temperature differences of variable nature, for the first galvanometer system is extremely sensitive to such effects. Apart from the advantage gained by the fairly low resistance of the circuit, there is a further advantage in that there is no material or electrical energy coupling between the first galvanometer system and the amplifier.

It is, of course, not possible to use the system for alternating current of period comparable with the period of response of the apparatus (about 3 seconds), for in that case a true indication of the time-current course would not be obtained. For the purpose of measuring very small currents of a direct or integrated nature the system lends itself admirably and has possible uses in the measurement of very feeble signals.

The first galvanometer may, of course, be used in connection with a vacuum junction for the measurement of very weak alternating currents.

The Photo-electric Cell Method.

We must now describe the method of current amplification using the photo-electric cell.

Photo-electric cells have come into the limelight recently because of their applications in television.

In general terminology all vacuum or gas-filled metal electrode cells, or selenium cells, are termed photo-electric cells because they function by means of an electrical charge brought about by the effect of light. In the present article it is only the first type of cells that concerns us.

When light falls upon a metal, electrons or negative particles of electricity are given off from the surface of the metal, to the surrounding space. This loss of electricity from the metal causes it to acquire a positive charge which increases as more electrons are emitted. Finally, however, emission is stopped because of the electrical attraction between the positively charged body and the negatively charged electrons, which tends to prevent the escape of the electrons. The action will continue nevertheless provided the metal is kept negatively charged or put into a suitable electric field (this can be effected by placing a positively charged conductor near to the metal and maintaining a positive difference of potential between them), helping the electrons to escape from the metal surface.

In the case of ordinary metals such as copper and iron, an appreciable electronic emission is brought about only by the action of ultra-violet light, but with the alkali metals sodium, potassium, rubidium and cæsium, ordinary light is effective in producing a considerable photo-electric effect (*i.e.*, a giving off of electrons). Consequently alkali metals are employed for the sensitive types of photo-electric cells.

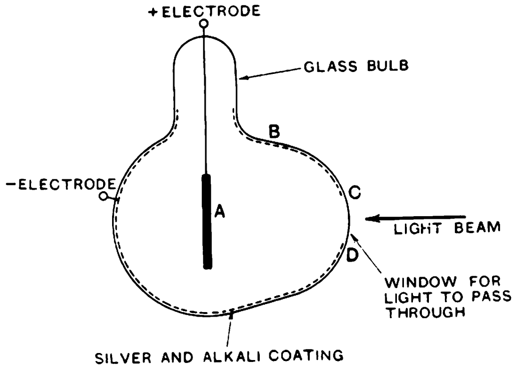


Fig. 7.

As is well known the alkali metals oxidise very rapidly in air (often taking fire) so that it is not possible to use them exposed to the atmosphere. They must consequently be enclosed in vacuum or in an inert gas that does not attack them.

Fig. 7 shows diagrammatically a typical form of photo-electric cell. A metal electrode *A* is mounted in a glass bulb *B* which is silvered on the inside except for a small part *CD* through which the light can enter. A layer of alkali metal, potassium or cæsium, is distilled upon the silver surface, and the bulb is either evacuated or filled with an inert gas.

Fig. 8 shows the experimental circuit employed. The cell is connected in series with a battery *B* and a galvanometer *G*, the cathode of the photo-electric cell (that is the negative pole) being the alkali metal surface. When light enters into the cell through the window and falls on the alkali metal surface *B*, electrons are given off by the photo-electric action of the light and these are collected by the positively charged electrode *A*. A current is indicated by the galvanometer *G* and if the voltage of the battery *B* is adjusted to be sufficiently high and the cell is a vacuum one, there will be a saturation current arrived at. This saturation current is found to be (within wide limits) proportional to the intensity of the light falling upon *B* and, for a given intensity, is greater the less the wavelength of the light producing the effect.

Such cells may be made still more sensitive by introducing a rare gas such as helium or argon into the tube, to a pressure of a few mms. of mercury. The electrons originally given off at the metal surface of *B* acquire a velocity under the action of the electric field between *A* and *B* and collide with atoms of the rare gas in such a way as to frequently split the gas atom into two portions, one of which is an electron and the other the residue of the atom, a positive ion. These new electrons in their turn produce further electrons, so that very considerable magnification of the original current may be obtained in this way. The extent of the magnification depends upon the voltage of the battery *B* and is greater the higher the voltage. Indeed, at sufficiently high voltages, a visible glow discharge may pass through the cell. This, of course, must be avoided, and in any case the performance of the cell is unreliable and unsteady if the battery voltage is in the vicinity of this "sparking" or discharge value.

In a recent communication to the *Journ. Opt. Soc. Am.* (May, 1926, Vol. 12, No. 5, p. 521), Null, following a suggestion of

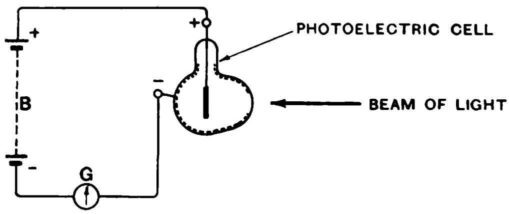


Fig. 8.

Tykociner and Kuntz, has described a method for the linear amplification of galvanometer deflections by the photo-electric cell, closely analogous to the thermo-relay method described above.

The image of the rectangular slit (no cylindrical lens is used) is projected upon a triangular slit which is placed before the window of the photo-electric cell (see Fig. 9) in such a way that an increased deflection

of the mirror of the first galvanometer brings about an increased illumination of the cathode of the cell, and a consequent increase of the photo-electric emission, resulting in an increase of the deflection of the second galvanometer.

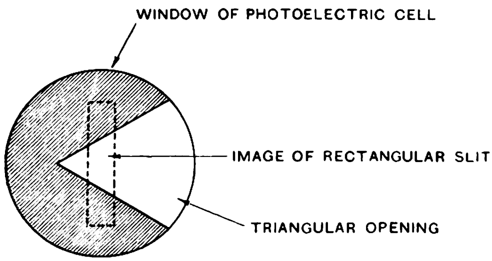


Fig. 9.

Null found, using one of the ordinary type of Kuntz cells, that a very accurate linear amplification was obtained. In his experiments only a weak beam of light was used (about 7×10^{-3} lumens), and the amplification was 1.85 mms. deflection of the second galvanometer per minute of arc. He points out that by increasing the light intensity ten times and making the angle of the slit twice as large (it was 17°15′) and increasing the distance between the galvanometer and the photo-electric cell three times (distance was about 105 cms.) an amplification corresponding to 1.85 mm. deflection per second of arc of the first galvanometer could be obtained (60 times larger than the previous figure).

The amplification factor can, of course, be varied at will by altering the intensity of the light source or the angle of the slit.

The method has the advantage that there is no lag in the photo-electric cell, and no trouble is caused due to small temperature changes. Null points out that the method is applicable for the linear amplification of very short period instruments. Further, by amplification of the photo-electric cell current by means of a three-electrode valve he was able to amplify the movements of the syphon recorder used in ocean cable signal reception.

Abstracts and References.

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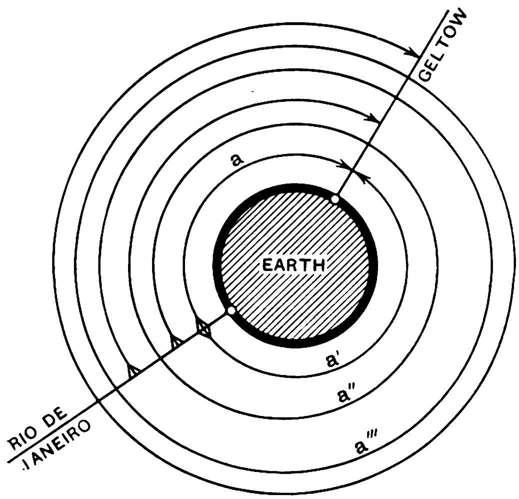
PROPAGATION OF WAVES.

WEITERE MITTEILUNGEN ÜBER DIE AUSBREITUNG VON KURZWELLEN (Further results on the propagation of short waves).—E. Quäck. (*Elektrische Nachrichten-Technik*, 4, 7, pp. 308-312, and *Zeitschr. für Hochfrequenz.*, 30, 2, pp. 41-42.)

In an earlier paper (*Zeitschr. für Hochfrequenz.*, 28, 6, p. 177; see Editorial *E.W. & W.E.*, May, 1927, p. 257) the author reported the occurrence of double signals during oscillographic reception of short waves at Geltow, when the time of arrival of the echo signal after the main signal permitted the conjecture that the echo signal had travelled in the opposite direction round the earth. The present paper gives the results of further observations at Geltow, when signals were not only received



Where a *is the path taken by the direct signal,*
a′ *the path taken by the signal travelling the opposite way round the earth,*
a″ *the path taken by the signal travelling in the same direction as the direct ray, but journeying further once completely round the earth, and*
a‴ *a similar path to this latter except that the waves encircle the earth twice before being recorded.*

twice, but several times, the differences in the time of arrival of the additional echo signals (practically always about .137 sec.) corresponding to a journeying of the waves in the same sense as the direct signal, but further right round the earth, either once or a succession of times, before being recorded. The different paths believed to be taken by the waves in the case of a triple echo effect is shown diagrammatically.

The figure refers to the beam transmission from Rio de Janeiro, and it is remarkable that waves should take a path round the earth in the opposite direction to the direct signal, when the transmitter is not only directional but works with a reflector. The wavelength is 15.66 metres; the range in which double signals have been detected up to now is between 14 and 34 metres. While echo signals that have taken the opposite way round the earth are found in the daytime, it seems that those due to the waves completely encircling the earth chiefly occur when the great circle between transmitter and receiver lies in twilight. The energy the signals still possess after repeatedly encircling the earth is astonishing, and it is concluded that many more encirclings occur than have been observed.

For the practical application of short waves, however, ways and means must be found of eliminating the disturbances caused by the double signals, also their systematic observation will contribute to elucidating our views on short-wave propagation.

IONISATION IN THE UPPER ATMOSPHERE.—E. O. Hulburt. (*Nature*, 6th August, 1927, p. 187.)

Re-examination of the causes of ionisation in the upper atmosphere, owing to the more definite information about that ionisation recently obtained from experiments with wireless waves together with theories of their propagation over the surface of the earth.

Of the more important agencies which may conceivably cause the ionisation of the earth's upper atmosphere—namely, ultra-violet light and α and β particles of solar origin, the penetrating radiation of cosmic origin, and the ionising radiations from terrestrial sources, the sun's ultraviolet light is chosen as deserving first consideration, owing to the diurnal variation in the ionisation.

Calculation, however, assuming classical pressures for the constituent gases of the upper atmosphere, leads to results which are at variance with night-time wireless data, and assuming greater than the classical pressures, still conflicts with Appleton's observations on 400 metres, which give an electron density of the order of 10^3 at about 100 km. for a June night (the calculation wiping out all night-time ionisation below 130 km.). Like this, an irregularity in the pressure-height curve may be supposed showing a maximum at about 100 km., or an ozone layer may be assumed at this height, which disintegrates slowly to oxygen during the night, thereby maintaining the ionisation; or again, such hypotheses may be discarded and, assuming classical pressures, the existence of other agencies of ionisation considered, besides ultra-violet light which are effective by night as well as by day.

The author details the many possibilities that may have to be reckoned with before theory on the ionisation of the upper atmosphere is brought into satisfactory accord with the requirements of wireless experiment.

THE EXISTENCE OF MORE THAN ONE IONISED LAYER IN THE UPPER ATMOSPHERE.—E. V. Appleton. (*Nature*, 3rd September, 1927, p. 330.)

Brief discussion of the results of many determinations of the equivalent height of the Kennelly-Heaviside layer, made at Peterborough, during systematic observation of wireless waves deviated by the upper atmosphere; for the past year and a half.

The results in question are that while the early summer observations of 1926 showed the night-time height of the deviating layer, for wavelengths of 400 metres, to be usually 90-130 km., those made during the period, October, 1926, to May, 1927, gave heights of an entirely different order of magnitude—namely, 250-350 km.—for the three hours before dawn. The evidence indicates that at these hours the ionisation in the Kennelly-Heaviside layer is sufficiently reduced by recombination to permit of its penetration by waves of this frequency, reflection taking place, however, at an upper layer which is richer in ionisation. With the advent of sunrise at a height of 100 km. or so, the Kennelly-Heaviside layer is formed again and deviation by the lower layer is suddenly re-established. As the day proceeds, the experimental results further suggest that another region of ionisation is formed below the Kennelly-Heaviside layer, which, while causing attenuation of the waves, does not very materially affect the height at which they are deviated.

DISCUSSION ON LONG DISTANCE RECEIVING MEASUREMENTS AT THE BUREAU OF STANDARDS IN 1925 (L. W. Austin).—G. W. Pickard. (*Proc. Inst. Radio Engineers*, 15, 6, June, 1927, pp. 539-540.)

The remarks refer to Mr. Sreenivasan's discussion of Dr. Austin's paper in the Proceedings for last February, and raise the question whether 1926 was not an exception to the general rule, apparently showing, for distant long-wave stations, an inverse instead of a direct relation between sunspots and day reception.

ATMOSPHERIC OZONE AND SOLAR VARIABILITY.—H. Clayton. (*Nature*, 30th July, 1927, p. 153.)

A brief survey of the correlation that has been found between solar changes and terrestrial phenomena, including the amount of ozone in the earth's atmosphere and variation of radio reception.

ZUR FORTPFLANZUNG ELEKTROMAGNETISCHER WELLEN LÄNGS LEITERN (On the propagation of electro-magnetic waves along conductors).—E. Roessler. (*Elektr. Nachr.-Technik*, 7, 4, pp. 281-295.)

By increasing the ratio of wavelength to the distance apart of double leads (two wires or earth and wire), the telegraph equation eventually loses its validity since radiation comes in. Mathematical treatment of the borderline region between conduction and radiation presents considerable difficulty, also its investigation experimentally is not easy. The importance of this region, however, has increased enormously with the employment of short waves. For instance, if the wavelength of a perpendicular antenna be diminished by exciting it in ever higher harmonics, the radiation will lose more and more in significance and the conduction of energy along the wire play the chief part. A limiting value must eventually be approached which has been theoretically calculated by Sommerfeld (*Wied. Ann.* 67, 233, 1899). However in all mathematical treatment of the subject hitherto, the conductors have been considered infinitely long. It is here shown that this assumption cannot be fulfilled in practice and that the values found experimentally differ considerably from the theoretical ones. The divergence can be already demonstrated with Lecher wires or high tension leads of ordinary dimensions. With right definition, however, the concepts of the telegraph equation can be generalised as is illustrated by reference to an antenna.

DU MILIEU ÉTHÉRÉ (On the ether medium).—L. Garrigue. (*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 22-23.)

Philosophical discussion resulting in the conclusion that the earth is enveloped by two kinds of ethereal waves: waves rolling in from outer space which push the earth towards the sun, and waves emanating from the earth itself which drive back the previous waves to the upper atmosphere. The author states that it is in this struggle, where one of the combatants has energies that are variable in time and space, that we shall find the explanation of the regular propagation of the Hertzian wave from our transmitting stations and also of its irregularities such as fading. It is also stated that the reason why our wireless waves travel better by night than day is because at night they are not broken by the Hertzian waves from the sun. A further contribution is promised.

ATMOSPHERIC ELECTRICITY.

EXTRACT FROM THE ANNUAL REPORT OF THE DIRECTOR (L. A. BAUER) OF THE DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON, FOR THE YEAR 1925-1926.—(*Journ. Franklin Institute*, July, 1927, p. 139.)

"While, on the average, there is a very high correlation from year to year during the 11-year solar cycle between sun-spottedness and the earth's magnetic disturbances, the correlation does not seem to be indicative of immediate cause and corresponding effect, but rather that sunspots, solar prominences, etc., and magnetic storms are all effects of one, as yet undiscovered, cause which may simultaneously affect the condition of the entire sun. However, there is another type of disturbance shown by fluctuations in the earth's magnetism, earth-currents, atmospheric electricity, and polar lights, revealing a double periodicity in the course of the year, which has not yet been satisfactorily explained by changing sun-spottedness or changing efficiency of a given sun-spot area

during the year. We are dealing here with effects resulting from the annual motion of the earth around the sun. It may turn out that because of the fact that the earth acts like a great magnet and behaves like a great electroscope, we have brought to us daily on the strips of paper wound around the recording drums of magnetographs and of electrographs, photographic evidences of solar and cosmical changes which other means fail to reveal to us in their entirety. And judging from reports received during the present period of marked increased solar activity, radio-reception measurements may effectively supplement the magnetic and the electrical data."

POTENTIALS DURING THE SOLAR ECLIPSE.—E. Owen and H. Jones. (*Nature*, 23rd July, 1927, p. 120.)

A diagram is shown giving the potentials recorded on 28th, 29th and 30th June, at a point 215 cm. above the ground. It is seen that during the eclipse there was a change from a positive to a negative potential, this change being probably due to the heavy rain which fell at the time.

PROPERTIES OF CIRCUITS.

A MATHEMATICAL STUDY OF RADIO-FREQUENCY AMPLIFICATION.—V. Smith. (*Proc. Inst. Radio Engineers*, 15, 6, June, 1927, pp. 525-536.)

There are two general methods of radio-frequency amplification, tuned and untuned. The latter is seldom used except in superheterodyne circuits in conjunction with one or more tuned units or a band pass filter to provide the selectivity. Theoretically, this untuned superheterodyne with a band pass filter is the best type possible. However, the voltage amplification of the untuned type of transformer is at present very unsatisfactory, as valve and winding capacities are exceedingly troublesome.

There are two methods of tuning in use. We may either tune the frequency to the circuits or the circuits to the frequency. The first is the superheterodyne method and the second is the common method of the neutrodyne and similar circuits.

It is this latter type that the mathematical discussion given here particularly concerns. Throughout a steady state is assumed, leaving transients for further consideration. This assumption permits the application of the ordinary vector methods of alternating current theory.

MEASUREMENTS OF RADIO-FREQUENCY AMPLIFICATION.—S. Harris. (*Proc. Inst. Radio Engineers*, 15, 7, July, 1927, pp. 641-648.)

Description of a method of measuring high-frequency amplification, applying accurately only to non-regenerative receivers. The method has the advantages that the measurements are independent of the values of the input and output voltages and do not require the removal of the stage in question from the receiver, being made under actual operating conditions. The same arrangement can be used for studying the gain-per-stage, the over-all characteristics of a receiver and valve detection coefficients.

GRID SIGNAL CHARACTERISTICS AND OTHER AIDS TO THE NUMERICAL SOLUTION OF GRID RECTIFICATION PROBLEMS. Part II.—W. Barclay. (*E.W. & W.E.*, September, 1927, pp. 552-558.)

L'AMPLIFICATION BASSE FRÉQUENCE À IMPÉDANCE (Low frequency impedance amplification).—P. Olinet. (*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 29-34.)

Mathematical study of a system connected by impedance, comparing it with a resistance-connected arrangement. The characteristics of the resistance circuit arrangement are high plate tension, absolute purity and low amplification. In the case of impedance it is found, on the contrary, that the system operates with normal tension, that of the battery being wholly applied to the plate, while the amplification is of the same order of magnitude as with resistance. While the purity is less than with the resistance system, it remains excellent if care is taken to keep far from the saturation point of the iron core.

HYSTERESIS IN VACUUM TUBE OSCILLATORS.—L. S. Taylor. (*Journ. Franklin Institute*, August, 1927, pp. 227-230.)

The paper deals with a further investigation of the groups of low-frequency oscillations produced when a condenser and resistance are placed in the grid circuit of a triode oscillator. These groups of oscillations are called by the author "zules." An empirical formula for their frequency and a theoretical study of their production are given in a previous paper by the author (*Journ. Frank. Inst.* 203, 351, 1927). The theory is experimentally checked here by means of observations with a cathode-ray oscillograph with a linear time axis. The envelope of the grid potential variations over the "zules" and the hysteresis action taking place through the depression of grid potential are indicated by various diagrams.

THE VACUUM TUBE OSCILLATOR.—D. Bourgin. (*Physical Review*, 29, 6, p. 912, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

The functional dependence of total filament-emitted current on grid and plate voltages is formally approximated by

$$i_p + i_g = A[1 - \exp.\{-(E_p + \mu E_g)^2\}]$$

for $E_p + \mu E_g > 0$, where A is the saturation value of the current and the other symbols are standard notation. This relation is made the basis for the "second order" treatment of the Hartley oscillator. By applying Kirchhoff's laws to the equivalent network, three simultaneous differential equations of the third order are derived connecting the variable grid and plate voltages and currents, and the current in the oscillatory circuit.

A VALVE AMPLIFIER FOR IONISATION CURRENTS. C. E. Wynn-Williams. (*Proc. Cam. Phil. Soc.*, July, 1927. pp. 811-828.)

A method of using a valve for amplifying ionisation currents 100,000 times is described, the system of compensation being applicable to other valve circuits, resulting in a much steadier zero.

On a Graphical Solution of an Electric Circuit containing Variable Constants.—I. Yamanoto. (*Journ. Inst. Elect. Eng., Japan*, No. 467, pp. 583-594.)

TRANSMISSION.

Some Practical Aspects of Short-Wave Operation at High Power.—H. E. Hallborg. (*Proc. Inst. Radio Engineers*, 15, 6, June, 1927, pp. 501-517.)

Propagation data over the frequency range of 3,000 to 30,000 kilocycles are submitted. A correlation is shown between wave frequency and angle of projection of the wave front, the effect of ionisation on the angle of projection is indicated, and some calculations are given of probable values of attenuation constant. The importance of frequency stabilisation is discussed and three typical circuits for utilising control crystals are described. Features of the design and adjustment of a 20kW power amplifier are outlined. Antenna and antenna feed systems are discussed and graphical results of comparisons of various antenna types are given.

RECEPTION.

L'Amplification sans Lampe (Amplification without a valve).—F. Michaud. (*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 9-15.)

Discussion of a new method of amplification utilising mechanical energy.

Speech Characteristics.—G. G. F. Dutton. (*Wireless World*, 3rd August, 1927, pp. 143-144.)

Discussion of transients and their relation to good articulation in telephony.

VALVES AND THERMIONICS.

The Performance of Reflexed Valves.—D. Kingsbury. (*E.W. & W.E.*, September, 1927, pp. 547-551.)

Transmitting Valves for Ultra-short Waves. (*Wireless World*, 10th August, 1927, pp. 180-183.)

The characteristics of the American valve UX-852 are given, with suitable circuits for 5, 15 and 80 metres.

Les Lampes de Puissance (Power valves). (*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 27-28.)

It is shown that a good output valve must be able to carry satisfactorily a large negative grid tension and that the inclination of its characteristic to the horizontal must be considerable. The data are given of the new type of valve Philips B403 which answers to these requirements.

Space Charge as a cause of Negative Resistance in a Triode.—L. Tonks. (*Physical Review*, 29, 6, p. 913, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

Oscillations occurring in a tuned circuit connected to grid and plate of a triode have been obtained by Gill when the grid potential was 40 volts and plate potential 8 volts. These were ascribed to unstable space charge in the tube. In the paper referred to here the mathematical theory for the case of plane parallel electrodes is first presented and later applied qualitatively to the case of cylindrical electrodes. The existence of a virtual cathode may cause negative resistance in both plate and grid circuit under emission limited operation, but for the case of space charge limited operation negative resistance is at most very small. The theory has a possible bearing on very short wave generation by the method of Barkhausen and Kurz.

Theory of the Shot Effect.—H. Wheeler. (*Physical Review*, 29, 6, p. 903, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

The shot effect, described by Schottky, is defined as the phenomenon of current fluctuations in a stream of electrons limited by random emission, as from a hot filament. Previous derivations of the magnitude of the shot effect have been based on equations deduced from the theory of probability. In the paper referred to here, a simple derivation of the equation $(I_0^2)_{\text{mean}} = eI_a/2RC$ (I_a = average space current), is given in terms of the familiar discharge current in a simple series circuit (R_1C_1L). This is followed by a Fourier integral derivation of the continuous frequency spectrum of the current fluctuations.

Electron Emission and Diffusion Constants for Tungsten Filaments containing various Oxides.—S. Dushman, D. Dennison and N. Reynolds. (*Physical Review*, 29, 6, p. 903, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

Surface Layers produced by Activated Nitrogen.—C. Kenty and L. Turner. (*Physical Review*, 29, 6, p. 914, June, 1924.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

Among other results, it is found that active nitrogen causes a large reduction of the thermionic current from a tungsten filament.

O- and N-Energy Levels in the Secondary Emission of Hot Tungsten.—H. Krefft. (*Physical Review*, 29, 6, p. 908, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

MEASUREMENTS AND STANDARDS.

On the Control of the Frequency of Flashing of a Neon Tube by a Maintained Mechanical Vibrator.—W. A. Leyshon. (*Philosophical Magazine*, August, 1927, pp. 305-324.)

Theoretical and experimental discussion showing

that the action of a tuning-fork in holding constant the frequency of flashing of a neon tube may be considered, to a first approximation, as being due to the introduction of a sinusoidal voltage of constant frequency and variable phase into the neon-tube circuit, this voltage being introduced electromagnetically into the circuit by the motion of the prongs of the fork, and the phase of this voltage adjusting itself so that the frequency of flashing is equal to the frequency of vibration of the fork. The theory is applicable to the case of vibrators maintained electrostatically, *e.g.*, a piezo-electric crystal in parallel with the condenser. Also a similar theory would explain, to a first approximation, the control of frequency of a multi-vibrator circuit by an introduced sinusoidal voltage.

Quantitative Determination of Radio Receiver Performance.—H. D. Oakley. (*Journ. Amer. Inst. Elect. Engineers*, 46, 6, pp. 568-572.)

Description of apparatus developed to overcome the difficulties encountered in making quantitative measurements on receivers as a whole. The over-all characteristics of receivers are classified and the method of making tests explained, the results obtained being shown by means of curves.

High Frequency Resistance.—A. G. Warren. (*E.W. & W.E.*, September, 1927, pp. 522-534.)

A Constant Frequency Source and its Frequency Measurement.—S. Pack. (*E.W. & W.E.*, September, 1927, pp. 535-546.)

The Piezo-electric Resonator.—Y. Watanabe. (*Journ. Inst. Elect. Eng. Japan*, No. 466, pp. 506-528.)

From the properties of the motional admittance-circle diagram of the piezo-electric resonator, its electrical equivalent constants can be determined. In this paper the writer firstly deals with some new methods of measuring motional admittance that he has devised and then investigates the characteristics of the resonator for several special cases.

Characteristics of the Piezo-electric Coupler.—Y. Watanabe. (*Journ. Inst. Elect. Eng., Japan*, No. 466, pp. 529-537.)

The "coupler" consists of one piezo-electric resonator and two pairs of electrodes, one pair for vibrating the resonator, and the other for producing a potential difference across the secondary impedance connected between these electrodes. Such a coupler is used in a piezo-oscillator and this paper deals with its equivalent circuit, verifying by experiment the results obtained mathematically.

L'Etalonnage des Circuits Intermédiaires de Moyenne Fréquence dans les Postes à Changement de Fréquence (The calibration of intermediate circuits of medium frequency in receivers with change of frequency).—J. Quinet. (*Radio-Revue*, August, 1927, pp. 421-424.)

Mesure des Pertes dans les Isolants en Haute et Moyenne Fréquence (Measurement of insulation losses at high and medium frequency).—J. Granier. (*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 5-8.)

In an oscillatory circuit, resonance is the more distinct and amplification the greater, the smaller the damping; this latter arises in large part from the resistance of the coils, which increases with the frequency, but the quality of the condenser is not immaterial. This article outlines how its effect may be determined, numerical results being left for a later paper.

Note on the Measurement of Dielectric Losses and Permittivity at Radio Frequencies.—R. Wilmotte. (*E.W. & W.E.*, September, 1927, pp. 569-570.)

La Mesure des Faibles Déphasages au Pont de Wheatstone (Measurement of small phase displacements by means of the Wheatstone bridge).—J. Granier. (*Q.S.T. Français et Radio Electricité Réunis*, 37, pp. 79-82.)

SUBSIDIARY APPARATUS.

The Oscilloscope: a Stabilised Cathode-Ray Oscillograph with Linear Time-Axis.—F. Bedell and H. Reich. (*Journ. Amer. Inst. Elect. Engineers*, 46, 6, pp. 563-567.)

Description of a method of using a cathode-ray oscillograph for the simultaneous observation of a number of variable quantities by means of a distributor. A linear time-axis, obtained by means of a gas-discharge lamp connected to a source of direct current through a resistance or valve, is stabilised by introducing into this circuit a small E.M.F. derived from the same source that supplies the unknown quantities under observation. The unknown quantities are thus shown in a form convenient for observation, appearing as stationary curves plotted with time as abscissa. The curves may be superposed about a common zero line, or displaced with reference to each other with separate zero lines.

A Device to draw Characteristic Curves of Vacuum Tubes automatically.—G. Campbell. (*Physical Review*, 29, 6, p. 913, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

Employing the usual circuit for obtaining characteristic curves, the grid-potential is varied continuously throughout the desired range by a modified W. G. Pye drum rheostat of the potentiometer type driven by a synchronous motor through speed reducing gears. A Leeds and Northrup recording pyrometer of the potentiometer type, connected across a standard resistance in the plate circuit, automatically draws the grid-potential plate current curve in rectangular co-ordinates.

Selective Morse Recording.—G. C. Blake. (*Wireless World*, 17th and 24th August, pp. 213 and 251 respectively.)

Some further notes on the hot-wire microphone and audio-resonant selection (see *E.W. & W.E.*, August, 1927).

WIRELESS AUTO-ALARM DEVICES.—(*Electrical Review*, 26th August, 1927, pp. 362-364.)

Some details are given of new apparatus designed for the automatic reception of radio-telegraph signals from ships in distress at sea.

REMOTE INDICATING AERIAL AMMETER.—A. P. Castellain. (*Wireless World*, 10th August, 1927, pp. 162-164.)

Description of an instrument that does not increase aerial circuit resistance.

TRICKLE CHARGER FOR H.T. ACCUMULATORS.—N. Vincer-Minter. (*Wireless World*, 3rd August, 1927, pp. 147-149.)

RADIO BATTERY ELIMINATORS.—P. Tyers. (*Electrical Review*, 5th August, 1927, p. 217.)

Some observations on the identification of suitable types, and the reasons that necessitate the exercise of care in their selection.

COMPARAISON DES DIVERS TYPES DE CONDENSATEURS VARIABLES (Comparison between the different types of variable condensers).—C. Reinewald. (*Q.S.T. Français et Radio Electricité Réunis*, 37, pp. 64-66.)

DIRECTIONAL WIRELESS.

ON THE WIRELESS BEAM OF SHORT ELECTRIC WAVES (VII.) (A new electric wave projector).—S. Uda. (*Journ. Inst. Elect. Eng., Japan*, No. 467, pp. 623-634.)

When several wave directors are arranged along a line at intervals equal to or greater than a quarter wavelength, the wave energy is transmitted chiefly along this line, the row of directors forming what is called a "wave canal." The projection of the sharpest beam is effected by combining a trigonal reflector with a wave canal. The directivity can be improved by increasing the number of director rods in the wave canal: for instance, with 27 directors the radiated power is confined almost to an angle of 5 degrees.

APPAREILS INDICATEURS DONNANT PAR LECTURE DIRECTE LA DIRECTION D'UNE ONDE (Indicating apparatus from which the direction of a wave can be read off directly).—H. Busignies. (*L'Onde Electrique*, 6, 67, July, 1927, pp. 277-303.)

Apparatus of the "Hertzian compass" type is stated to have very special application and must not be confused with the radiogoniometer. The purpose of the radiogoniometer is to take bearings, for which use it is simple and practical, and the Hertzian compass offers no advantage over it, but the radiogoniometer cannot guide aircraft rationally towards its destination, which is claimed for the Hertzian compass, when adjusted to the wave of the transmitter at the landing station.

This paper discusses in detail two forms of the compass, together with the sensitivity, errors, etc. The apparatus, however, while working perfectly on the ground, has not yet become sufficiently evolved for installation on aircraft, and is still undergoing development (*cf. Radio-Revue* of last March, these Abstracts *E.W. & W.E.*, June, p. 372).

WIRELESS BEACONS.—(*Electrician*, 26th August, 1927, p. 251.)

Particulars are given of the first wireless beacon station to be put into regular commission which is situated at Round Island in the Scilly Isles. The set has a power of 500 watts and is operated on a wavelength of 1,000 metres. The beacon transmitter was designed by the Marconi Co. to the specifications of Trinity House. Similar installations for the assistance of navigation are now under construction at various points around the English coast.

THE POSSIBILITIES OF DIRECTIONAL RADIO TRANSMISSION.—J. H. Dellinger. (*Journ. Franklin Institute*, August, 1927, pp. 239-243.)

Abstract of address given before the Franklin Institute, 3rd March, 1927.

Considering first the limitations of directional radio, the author is of the opinion that the directing of radio waves in a very sharply defined beam, rendering individual communication possible, is never likely to be achieved. In the beam systems now utilised, the waves are not confined with extreme sharpness to the desired direction, and their chief advantage is an economic one rather than one of secret communication. The writer further says that the idea of transmission of substantial amounts of power to considerable distances by radio is ridiculous, also that picture telegraphy and television are not to be materially advanced by directional radio, all of which can best be carried on by the aid of conducting wires.

Coming now to the advantages, the writer allows that the remote control of distant objects, like machinery or ships, may be somewhat facilitated through the use of directional radio, but that this latter has attained its greatest success in the realm of navigational aids, and will unquestionably have a great future as an element in the safety of aviation.

GENERAL PHYSICAL ARTICLES.

ON THE WAVELENGTH OF THE GREEN AURORAL LINE IN THE OXYGEN SPECTRUM.—J. C. McLennan and J. H. McLeod. (*Proc. Royal Society*, A, 115, pp. 515-527, August, 1927).

The spectrum of the aurora is characterised by two outstanding features: a set of bands and a strong narrow sharply-defined green line. As to the bands, several investigators have shown them to be identical with the so-called "negative" bands obtained with molecular nitrogen in the singly-ionised state. Nitrogen in this state must, therefore, be one of the main constituents of that portion of the upper atmosphere in which auroral displays occur. As to the line, while Prof. Vegard has put forward the view that it originates in solid nitrogen suspended in a state of fine division in the upper atmosphere, and excited in some way to luminescence, others have maintained that it is due to the presence of oxygen.

The purpose of the investigation described in this paper is to make a precise determination of the wavelength of the oxygen green line and compare the value obtained with Dr. Babcock's accurate determination of the wavelength of the auroral green line.

The two values are found to be in such remarkable agreement that the oxygen green line and the auroral green line are concluded to be identical.

The bearing of the result on the constitution of the upper atmosphere is that oxygen as well as nitrogen is present in the region where the auroral light is emitted.

Die Wellenlänge der grünen Nordlichtlinie (The wavelength of the green auroral line).—G. Cario. (*Zeitschr. f. Physik*, 42, 1, pp. 15-21.)

The result of the author's measurement at Göttingen of the wavelength of the green line emitted by oxygen agrees so closely with Babcock's result for the auroral line that the identity of the two are regarded as established. The existence of oxygen in the upper atmosphere where the aurora originates, as well as nitrogen, appears therefore to be proved.

Zür Frage des Vorhandenseins von Festem Stickstoff in der Erdatmosph¨re (On the question of the presence of solid nitrogen in the earth's atmosphere).—H. Pelzer. (*Annalen der Physik*, 83, 3, June, 1927, pp. 362-384.)

With reference to Vegard's hypothesis concerning the aurora, it is investigated mathematically whether the upper layers of the atmosphere, in radiation equilibrium with terrestrial and solar radiation, can have a temperature below the melting point of nitrogen (30° K). The conclusion reached is that this temperature (for the night side of the earth as well) could only be attained by making suppositions that could hardly prove true, and that therefore Vegard's hypothesis is to be rejected if only for thermo-dynamical reasons.

An Effect of Sunlight on the Altitude of Aurora Rays.—C. Strömer. (*Nature*, 3rd September, 1927, pp. 329-330.)

Facts are enumerated tending to show that sunlight has a remarkable action on the upper atmosphere, rendering the illumination caused by the electric rays forming the aurora borealis visible to much greater altitudes than ordinarily. To account for this, the author suggests it may be that the accumulated ionising effect of the sunlight and of the electric rays illuminates the atmosphere to a greater altitude than the electric rays alone, or perhaps also the ionisation lifts up the atmosphere by electric charge, as in Vegard's theory, or that such a lifting up may be the effect of a raising of the temperature in those regions.

The Sun as a Research Laboratory.—G. E. Hale. (*Journ. Franklin Institute*, July, 1927, pp. 19-28.)

The Physical Form of Ether.—D. Meksyn. (*Philosophical Magazine*, August, 1927, pp. 272-300.)

The Physical Reality of Light Quanta.—M. Planck. (*Journ. Franklin Institute*, July, 1927, pp. 13-18.)

The Instantaneity of the Photo-electric Effect.—E. Lawrence. (*Physical Review*, 29, 6, p. 903, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

The paper referred to describes experiments which indicate that electrons start coming off a potassium surface the instant light falls on the surface and cease being emitted the moment the illumination is cut off, within a possible experimental error of 3×10^{-9} sec.

Ionisation by Collisions of the Second Kind in mixtures of Hydrogen and Nitrogen with the rare Gases.—G. Harnwell. (*Physical Review*, 29, 6, p. 906, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

Influence de la Fréquence sur les Pertes dans les Isolants (Influence of the frequency on insulation losses).—J. Granier. (*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 81-84.)

It is found that losses are chiefly of importance in insulators capable of absorbing moisture. The power lost is sensibly proportional to the frequency for all the waves employed in wireless telegraphy, but increases much less quickly than this at low frequency. The figures given in the tables that are reproduced can only show the order of magnitude, the properties of an insulator varying considerably from one specimen to another.

Insulation and Short Waves.—C. Forbes-Buckingham. (*Electrician*, 12th August, 1927, pp. 192-193.)

Account of the search for an ideal insulator for radio equipment, discussing the difficulties in oscillation control due to the insulating material and the effect of loading ebonite.

Insulators and Insulation.—J. Strachan. (*Wireless World*, August, 1927, pp. 169-170.)

Discussion of materials suitable for use in wireless receivers.

Maxwell's Theory of the Layer Dielectric. (*Journ. Amer. Inst. Elect. Engineers*, 46, 7, pp. 727-731.)

Discussion on Dr. Murnaghan's paper in *Journal A.I.E.E.* of last February, p. 109.

Undamped Extra-short Electromagnetic Waves obtained with the Magnetron.—K. Okabe. (*Journ. Inst. Elect. Eng., Japan*, No. 467, pp. 575-582.)

With the intensity of the magnetic field kept near its critical value and a high voltage applied to the anode, strong waves were obtained of length $\lambda_0 = 2ct$, where c is the velocity of light and t the time required by the electrons to travel from cathode to anode. The length of the shortest wave obtained was 17 cm.

MAGNETIC PROPERTIES OF IRON IN HIGH FREQUENCY ALTERNATING CURRENT FIELDS.—J. Martin. (*Physical Review*, 29, 6, p. 906, June, 1927.)

Abstract of a paper presented at the Washington meeting of the American Physical Society, April, 1927.

A number of investigators have studied the losses due to eddy currents and hysteresis in iron when placed in high frequency alternating current fields, but the results obtained are in wide disagreement. Using a new method, the author has investigated the variation of this loss with frequency for several areas of cross section. He finds the loss to increase with frequency in the small samples and to decrease with frequency in the larger: at any particular frequency the loss is an inverse function of the area. This is due to the magnetic shielding effect of eddy currents in the large samples and the disagreement between previous investigations may thus be explained.

THE EFFECT OF WAVELENGTH ON THE DIFFERENCES IN THE LAGS OF THE FARADAY EFFECT BEHIND THE MAGNETIC FIELD FOR VARIOUS LIQUIDS.—F. Allison. (*Physical Review*, 30, 1, pp. 66-70, July, 1927.)

The method of the experiment affords a means of measuring the ratio of the speed of electric impulses along copper wires to the speed of light. The value obtained for the ratio was about 96 per cent.

MAXIMISATION METHODS FOR FUNCTIONS OF A COMPLEX VARIABLE.—W. van B. Roberts. (*Proc. Inst. Radio Engineers*, 15, 6, June, 1927, pp. 519-524.)

The maxima and minima of a function of a real variable are found by equating to zero the derivative of the function. In the case of a function of a complex variable, however, the derivative is a vector quantity, so that conditions may be imposed upon its direction as well as upon its magnitude. These various conditions lead to maxima and minima of the various aspects of the function. Rules are developed for setting up equations giving the various maximising conditions, and a simple example is given illustrative of the use of each rule.

A MECHANICAL SYNTHESISER AND ANALYSER.—F. Kranz. (*Journ. Franklin Institute*, August, 1927, pp. 245-262.)

STATIONS: DESIGN AND OPERATION.

SHORT-WAVE COMMERCIAL LONG-DISTANCE COMMUNICATION.—H. E. Hallborg, L. A. Briggs and C. W. Hansell. (*Proc. Inst. Radio Eng.*, 15, 6, June, 1927, pp. 467-499.)

The development of short wave communication by the Radio Corporation of America is outlined, a summary of short wave installations, with call letters, wavelengths and services to which each installation is assigned, being given. Traffic charts showing the diurnal and seasonal characteristic of various wavelengths over typical circuits are shown. Technical problems inherent to the development of valves and transmitter circuits are discussed and methods for obtaining their proper operation at very short wavelengths described.

LES STATIONS DE BROADCASTING EUROPEENNES (European broadcasting stations).—*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 85-86.)

A list of 218 broadcasting stations in all parts of Europe is given, classified in the order of increasing wavelength, beginning with Joenkoeping (201.3 m.) and ending with Koenigswusterhausen (4,000 m.).

LA STATION FRANÇAISE DE ZI-KA-WEI (The French station at Zi-Ka-Wei).—(*Q.S.T. Français et Radio Electricité Réunis*, 37, pp. 59-63.)

Of the 20 stations on Chinese soil, 15 belong to China herself, while the remaining five are either French or American. After brief data concerning the Chinese stations, this article gives a detailed account of the French station at Zi-Ka-Wei, a small village 6 or 7 kilometres from Shanghai. The name Zi-Ka-Wei has become universally known owing to the part taken by its Observatory in the recent new determination of longitudes.

AMERICAN AIRCRAFT WIRELESS.—(*Wireless World*, 3rd August, 1927, pp. 139-140.)

Description of the apparatus on the "American Legion" transatlantic aeroplane, similar sets to which are being manufactured commercially for use on aeroplanes flying over the long-distance air-mail and other air routes in the United States.

AIRCRAFT RADIO EQUIPMENT.—(*Electrical Review*, 29th July, 1927, p. 198.)

Brief account of Marconi apparatus for use on transatlantic flight.

TRANSATLANTIC TELEPHONY.—(*Wireless World*, 31st August, 1927, pp. 274-275.)

Account of the two-way working on a single wavelength by means of speech-controlled relays.

MISCELLANEOUS.

REPORT OF COMMITTEE ON ELECTRICAL COMMUNICATION FOR THE PAST INSTITUTE YEAR.—H. P. Charlesworth. (*Journ. Amer. Inst. Elect. Engineers*, 46, 7, pp. 712-716.)

With regard to radio telegraphy, it is stated that long distance communication is rapidly changing from long waves generated by alternators or Poulsen arcs to short waves generated by valves. Within the last 18 months, transmitters up to 40kW. capacity operating on wavelengths of 30 to 15 metres, have been produced and put into service. These are replacing arc generators up to 500kW and alternators of 200kW capacity. Reliable continuous daylight communication has been obtained with wavelengths around 15 metres, notably between New York and Buenos Aires. During hours of darkness, wavelengths from 25 to 75 metres have been in use in both transatlantic and transpacific services. The greater reliability of the short waves is the result of almost complete immunity to summer static, also the new system is much more economical owing to the low power consumption compared with long wave transmission.

The report also contains brief paragraphs on transatlantic radio telephony, radio broadcasting, electrical transmission of pictures, and television.

WIRELESS BEAM STATIONS.—(*Electrician*, 2nd September, 1927, p. 287.)

On 25th August the announcement was made that the beam stations which have been built for the General Post Office by the Marconi Company at Grimsby and Skegness for communication with India have successfully passed their seven days' official test. The scheme to link up Great Britain with Canada, Australia, South Africa and India, by means of high-speed wireless telegraph services, decided upon by the Government in 1923, has thus been successfully completed.

It is further stated that before the end of next year there is every prospect of telephone subscribers in England being able to call up subscribers at any point in any of the Dominions by means of the beam system and that there is also the prospect of the transmission of written and printed matter, drawings and photographs.

GERMANY—RADIO TELEPHONY.—(*Electrical Review*, 12th August, 1927, p. 268.)

The first official attempt to speak by wireless telephone from Berlin to Buenos Aires, a distance of about 7,000 miles, was made during the evening of 3rd August. As there was no transmitter at Buenos Aires, speech passed in the outward direction only, and was uniformly good. The messages were spoken into a microphone at the Voxhaus, whence they were transmitted over land telephone lines to the Nauen wireless station, 20 miles north-west of Berlin, which radiated them by a special short-wave transmitter. The receiving station was at Villa Eliza, not far from Buenos Aires, the final stage being accomplished over the ordinary telephone lines. If the favourable results are fully confirmed, it is intended to institute a public service after proper equipment has been installed near Buenos Aires.

RUSSIA—LONG DISTANCE TELEPHONY.—(*Electrical Review*, 26th August, 1927, p. 350.)

The Mukden and Soviet authorities have concluded agreements for providing long-distance telephone services between Harbin and Chita and Harbin and Vladivostock. The total cost is estimated at $1,500,000 which will be borne equally by the Russian and Mukden authorities.

With regard to broadcasting stations, it is reported in the *Review*, of 29th July, that there are now 56 in operation in Soviet Russia, of which five are in Leningrad and nine in Moscow.

LA TÉLÉPHONIE SANS FIL PAR ONDES LUMINEUSES. (Wireless telephony by luminous waves).—M. Chauvierre. (*Q.S.T. Français et Radio Electricité Réunis*, June, 1927, pp. 49-54.)

The last part of a serial article considering chiefly Ruhmer's experiments between 1902 and 1907.

TELEPHONE COMMUNICATION OVER POWER LINES BY HIGH FREQUENCY CURRENTS.—C. A. Boddie. (*Proc. Inst. Radio Engineers*, 15, 7. July, 1927, pp. 559-640.)

THE USE OF HIGH FREQUENCY CURRENTS FOR CONTROL.—C. A. Boddie. (*Journ. Amer. Inst. Elect. Engineers*, 46, 8, pp. 763-769.)

PRESENT STATUS OF THE INTERNATIONAL ELECTRICAL UNITS.—E. C. Crittenden. (*Journ. Amer. Inst. Elect. Engineers*, 46, 8, pp. 769-775.)

WIRELESS NOTES.—(*Electrician*, 26th August, 1927, p. 267.)

The Wireless Section of the U.S.A. Patent Office has doubled in size in the past six years. Applications for wireless patents number approximately 125 per month, as compared with about 60 per month in 1921.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

RICEVADO.

LA FUNKCIADO DE REFLEKSAJ VALVOJ.—D. Kingsbury.

La aŭtoro priskribas efekton, observitaj ĉe refleksitaj cirkvitoj, de maldolĉa kaj profunda tono, obtenita kiam la malaltfrekvencaj transformatoroj konektitaj estas krucigitaj, la efekto estante detektita egale per du transformatoroj de malsama tipo. La tiam diskutas la efektojn de variado de anoda tensio kaj filamenta kurento, kaj sekvas la diversajn komponajn partojn de kurento kaj tensio necesigitaj en refleksa ricevado, kaj la efektojn produktitajn per variado de ĉi tiuj tensioj.

La traktado provizas interesan analizon de refleksa funkciado, kaj la artikolo finiĝas per utilaj notoj pri utiligo de l'efekto priskribita en la alĝustigo de refleksa aparato.

DESEGNO KAJ KONSTRUO DE SUPERHETERODINA RICEVILO.

Mallonga noto korektanta eraron en Fig. 13 de l'artikolo de S-ro. P. K. Turner pri ĉi tiu temo en antaŭaj numeroj, kaj reproduktanta la korektitan figuron.

KRAD-SIGNALAJ KARAKTERIZOJ KAJ ALIAJ HELPOJ JE LA NUMERA SOLVO DE KRAD-REKTIFAJ PROBLEMOJ.—W. A. Barclay.

Daŭrigita el la antaŭa numero, en kiu la aŭtoro konsideris la derivon kaj utiligon de kurvoj (obtenitaj el la kradkurenta karakterizo de valvo), al kiu li donis la nomon de Kradsignalaj Karakterizoj. En la numa parto li traktas pri plisimplaj metodoj derivi ĉi tiujn kurvojn kaj montras metodon uzantan duon-logaritme liniumitan paperon, per kio T-forma kursoro estas aplikebla al la logaritmaj kurvoj por provizi rektan montron de la informo donita de la kradsignalaj karakterizoj. Mallonga matematika pruvo de la metodo estas donita.

MEZUROJ KAJ NORMOJ.

ALTFREKVENCA REZISTECO.—A. G. Warren.

La aŭtoro unue konsideras la ekzemplon de induktanca bobeno en altfrekvenca cirkvito, kaj la malfacilaĵojn je altfrekvencaj mezuradoj, kaŭze de (1) neaplikebleco de metodoj taŭgaj por malaltaj frekvencoj, kaj (2) la "malpureco" de la kvantoj mezurotaj. La efekto de distribuita kapacito estas diskutita kaj bone ilustrita per vektoroj de la kurento en diversaj partoj de l'cirkvito.

La aŭtoro tiam traktas pri rezisteco de bobeno kaj pri l'efekto de alta frekvenco ĉe la rezisteco, kun aludo al la bone konata laborado de Howe kaj de Butterworth pri ĉi tiu temo. Diskutante praktikajn metodojn mezuri altfrekvencan rezistecon, oni esprimas preferon por kalorimetra metodo, per kio la kurento en la bobeno estas mezurebla, la varmeco produktita determinebla, kaj la rezisteco kalkulebla. Eraroj de kalorimetraj mezuroj estas diskutitaj, kaj la aŭtoro priskribas metodon kun la distingaj trajtoj, ke la komenca rapido de la temperatura altiĝo de diversaj partoj de la bobeno estas mezurita, tiel ebligante la eliminon de efektoj de variadoj de eksteraj termaj kondiĉoj, kaj la determinon de la rezisteco de diversaj partoj de la bobenoj. Oni donas detalojn pri kelkaj preparaj esploroj necesaj, kaj pri metodo determini la komencan rapidon de temperatura altiĝo. Tipaj eksperimentaj rezultoj estas montritaj kaj diskutitaj; kurvo aparte interesa montranta la distribuon de perdo en eksperimenta bobeno.

Plua etendo de la metodo de l'aŭtoro estas fine priskribita, ebligante facilan mezuron de la proporcio de alta je malalta frekvenca rezisteco.

NOTO PRI LA MEZURADO DE DIELEKTRIKAJ PERDOJ KAJ PERMESECO JE RADIO-FREKVENCOJ.—Raymond M. Wilmotte, B.A.

Oni montras, ke je ĉiuj mezuroj kun malgranda kapacitoj (de grandeco de 100 aŭ 200 $\mu\mu$F) la korekto por randa efekto povas esti tiel granda kiel 5 procento, kaj la utiligo de ŝirmilo kaj garda ringo estas rekomendita. Pontaj aranĝoj por malaltaj frekvencoj estas montritaj por utiligo kun garda ringo, kaj altfrekvenca metodo estas ankaŭ priskribita, kun notoj pri la konstruado de la garda ringo, farado de mezuroj, k.t.p.

HELPA APARATO.

KONSTANTA FREKVENCA FONTO KAJ ĜIA FREKVENCA MEZURADO.—S. W. C. Pack.

La fonto priskribita estas valve subtenita tonforko, kaj en la unua parto de la artikolo la principoj de la subtenado estas ripetitaj, inkluzive la utiligo de transformatoroj. La afero de konstanteco estas tiam pritraktita, la ĉefa faktoro de variado estante temperaturo, pro kiu kaŭzo la muntita forko devus esti an ĉelo de konstanta temperaturo.

La aŭtoro tiam priskribas, kun ilustraĵo, la muntadon kaj enfermigon de forko de 128 cikloj, kun rimarkigoj pri la desegno de la funkcianta valva cirkvito, alĝustigo de pozicio de la funkciiga bobeno, elekto de valvo, k.t.p.

Simpla traktado pri la teorio de la valve subtenita forko estas tiam donita, la traktado estante sugestita de Prof. E. Mallett kaj plivaste pritraktita de l'aŭtoro, kun notoj pri mekanikaj konsideroj, generita elektro-mova forto, movada impedanco, kalkulado de forkaj konstantoj, k.t.p.

La aŭtoro laste traktas pri metodo determini la frekvencon de la subtenitaj vibradoj, la metodo priskribita utiligante fonikan radan motoron. La konstruado de la fonika rado kaj ĝiaj funkciigaj bobenoj estas priskribita kaj ilustrita, kun diagramo de la kompleta cirkvito por subteni kaj determini la frekvencon.

ANĈA REKTIFIKATORO POR BATERIA ŜARGADO.—C. O. Browne.

Detaloj estas donitaj de simpla silenta kaj nesparkanta instrumento uzante vibrantan anĉon kaj hidrargan tasan kontakton. La konstruado de la anĉo estas priskribita kaj ilustrita, kun notoj pri la alĝustigo, kaj diagramo de konektiloj por duononda rektifado, k.t.p. Sugestita aranĝo por plenonda rektifado estas ankaŭ montrita.

DIVERSAĴOJ.

RESUMOJ KAJ ALUDOJ.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienco kaj Industria Esplorado.

MATEMATIKO POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto daŭrigas la traktadon de la Diferenciala Kalkuluso, traktante pri diferencigo de la sumo de nombro da funkcioj, diferencigo de funkcio de funkcio, normaj formoj, sinsekva diferencigo, krizaj valoroj, k.t.p.

LIBRO-RECENZOJ.

Recenzoj estas donitaj pri la jenaj verkoj :—

Navigational Wireless (Navigada Senfadeno) de S. H. Long, D.Sc., M.I.E.E. (Eldonistoj, Chapman & Hall, Londono.)

Esperimental Radio (Eksperimenta Radio) de R. R. Ramsey. (Eldonistoj, University Book Stores, Bloomington, Ind., Usono.)

Erratum.

The third paragraph of the Abstract of the paper entitled "Gittergleichrichtung," appearing on page 573 of the September number of *E.W. & W.E.* should read :—

"The increase in grid tension necessary to raise the grid current e-fold (where e is the base of the Naperian logarithm) is called the temperature tension."

Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

MULTI-STAGE VALVES.

(*Application date, 24th February*, 1926.
No. 271,558.)

Two sets of filament-grid-plate electrodes *F, G, D* are arranged side by side in the same bulb, and are held in position partly by wires *S* mounted as usual in the glass stub, and partly by wires S_1 depending from a glass pillar *M*. The lead-in wires to one set of electrodes are taken to the ordinary pins F_1, F_2, G_1, P_1 of a standard valve-mount as shown in Fig. 1, whilst the other set are taken to screw terminals mounted on the sides of the brass cap.

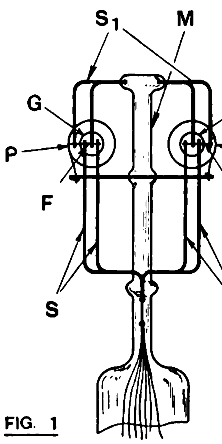


FIG. 1

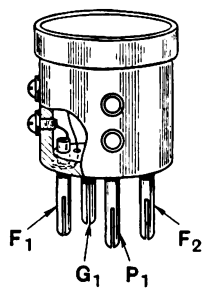


FIG. 2

The latter set of terminals are duplicated in order to allow selected electrodes to be connected either in series or in parallel to the external circuits. Thus the filaments may be fed in series or in parallel as desired, the valve may be connected up either for push-pull or cascade amplification, and the grids may be used independently as in dual or reflex amplification. These and other external circuit variations can be rapidly and conveniently effected without removing the valve from its holder. Patent issued to T. W. Lowden.

PHOSPHORESCENT FILAMENTS.

(*Convention date* (*Austria*), 21*st May*, 1926.
No. 271,401.)

The inventor, A. Just, states that certain sulphides, particularly such as exhibit the property of phosphorescence, possess an electron-emission equal to that of the alkaline-earth coatings or the thoriated-tungsten filaments usually employed for the dull-emitter type of valve. The sulphides of zinc, calcium, strontium and barium, mixed with traces of heavy metal sulphides, are stated to be suitable.

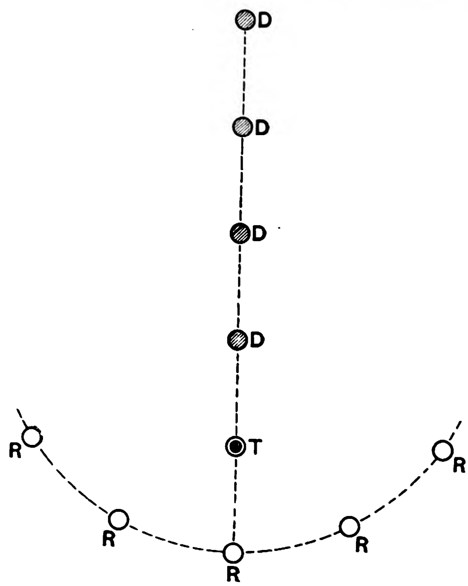
A metal filament of platinum or platinum iridium is first coated with calcium containing traces of copper or bismuth, and the coating is then converted by any known sulphurising process. Or the sulphides may be first applied to the wire as a direct coating, and then fixed in position by heating to incandescence in an atmosphere of nitrogen.

DIRECTIVE SIGNALLING.

(*Convention date* (*Japan*), 29*th December*, 1925.
No. 263,755.)

Directional effects are secured by combining a main oscillator or transmitting aerial *T* with a system of reflecting conductors *R* and "directing" conductors *D* in the manner shown in plan in the figure. The reflectors *R* are tuned to a frequency equal to or less than that of the signalling frequency, whilst the "directors" *D* are tuned to a higher frequency than that of the radiated wave.

Under these circumstances the current induced by the oscillator *T* in the directors *D* "leads" the voltage, whilst in the case of the reflectors *R* the



current "lags" behind the voltage. For this reason the Japanese inventor, Hidetsugu Yagi, states that the array of conductors *R* acts as a reflecting system, whilst the directors arranged along the line *D—D* serve as a wave duct or channel "favouring" the passage of the wave. In this way a definite path of maximum radiation or reception is secured.

HIGH-ANGLE RADIATION.

(*Convention date* (*U.S.A.*), 9*th May*, 1925. *No.* 251,946.)

In this patent the British Thomson-Houston Co., as assignees of E. F. W. Alexanderson, describe an aerial system which is designed to radiate energy at a high angle to the horizon, and with a substantial degree of horizontal polarisation, as distinct from the more usual type of vertically-polarised wave.

The simplest form of aerial is shown in Fig. 1, whilst an alternative arrangement is illustrated in Fig. 2. In Fig. 1 the radiators consist of two horizontal wires *AB*, spaced apart by half a wave-length and mounted at a height of at least one-eighth the signal wavelength above ground. In Fig. 2 the wires are replaced by vertical loops, the sides of which contain series condensers calculated to neutralise the effective inductance of the wires. In both cases the radiators are energised centrally from a power source *O* through leads containing phase-adjusting means P, P_1.

By adjusting the phase-changing devices P, P_1, the currents in both the radiators *A*, *B*, Fig. 1, may be arranged to flow simultaneously in the same direction. Under these conditions the effective radiation is vertically upwards. If, on the other hand, the current flow occurs in opposite directions, maximum radiation takes place upwards at an angle of 45° in the length direction of *A*, *B*. If the currents in the two loops of Fig. 2 are

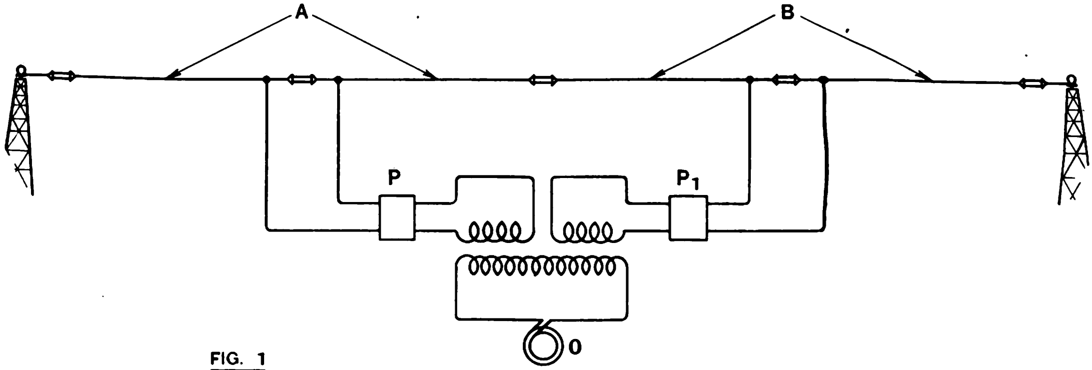


FIG. 1

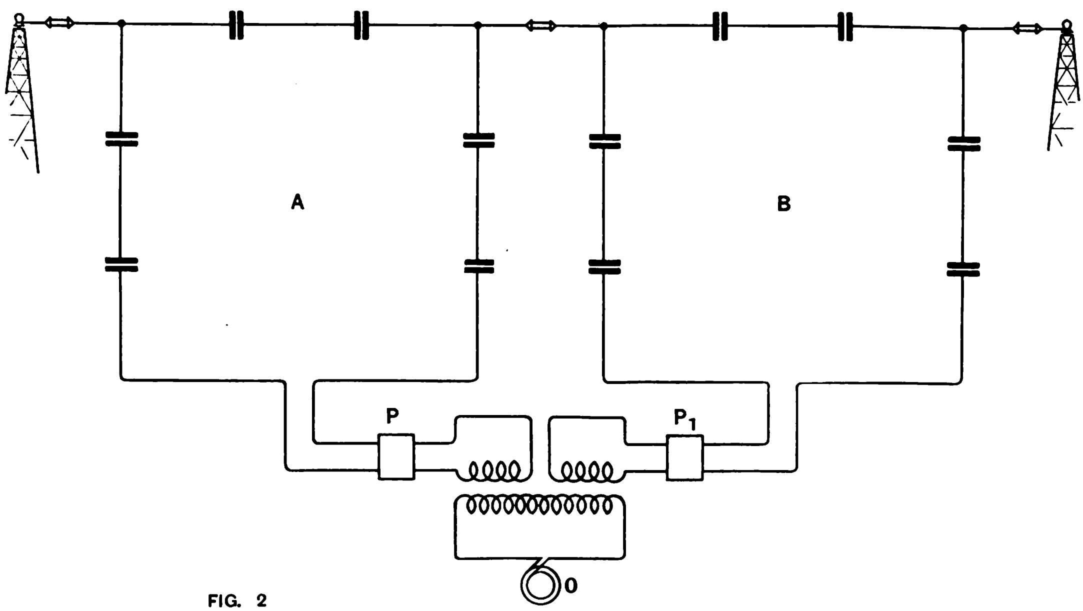


FIG. 2

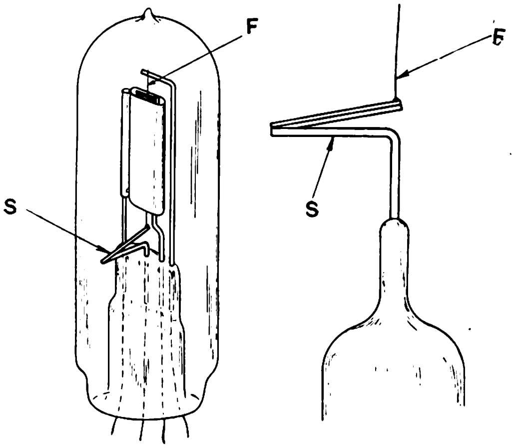
adjusted to flow clockwise simultaneously, all radiation from the vertical sides is neutralised and the system becomes equivalent to that of Fig. 1.

By using a "bank" of horizontal antennæ, the radiated beam is narrowed both in the horizontal and vertical directions.

AN ANTI-MICROPHONIC VALVE.

(*Application date, 8th March*, 1926. *No.* 271,584.)

Microphonic noise is frequently traced to the action of the springs used for tensioning the valve filament. In order to avoid this source of trouble,



Mr. E. Y. Robinson utilises a bimetallic strip *S*, shown separately in the side figure, which is so arranged that it is heated to substantially the same temperature as, or proportionately to, the filament, and supports the latter so as to keep it straight without actually tensioning it.

The strip may be heated either by radiation from the filament or by passing current through it. As shown, it is connected between the lower end of the filament and the lead-in wire. As the filament *F* expands under heat, the upper end of the strip *S* curls downwards so as to take up the slack. In the case of a filament of the hair-pin type the compensating strip is hooked under the bight of the loop and is supported in a suitable mounting near the nib end of the valve.

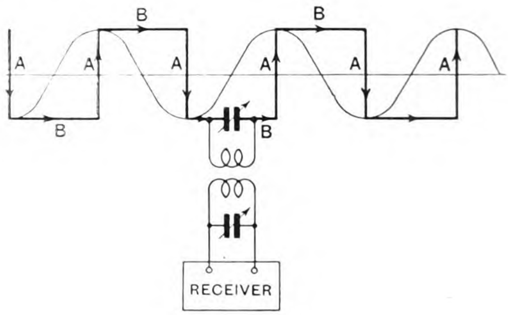
WAVE AERIALS.

(*Application date, 10th January*, 1927. *No.* 272,117.)

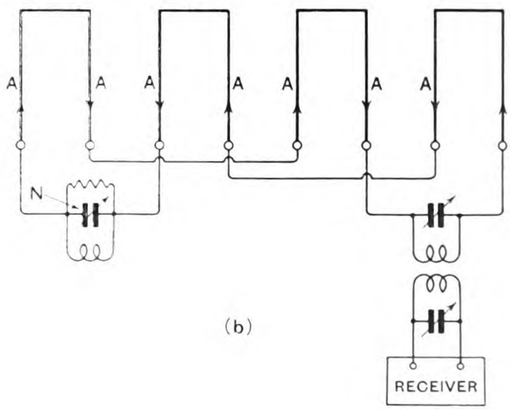
Standard Telephones and Cables, Ltd., describe an aerial system comprising a series of vertical wires *a* each having a height corresponding to an odd integral multiple of half the signal wavelength. The vertical elements are spaced apart by half a wavelength, and are connected in series by horizontal conductors *b*, so that the currents and voltages induced in each vertical are in phase with each other, but are in opposition to those in adjacent verticals, as shown by the arrows.

When the aerial system is in alignment with the direction of propagation of the signal wave, a directional effect is secured similar to that obtained in the case of the Beverage aerial, and depending upon the cumulative action of the induced "line" current and the external or ether-wave energy. Usually the line-wave velocity lags the space-wave velocity by an appreciable amount, and in order to avoid this limitation, the height of successive verticals may be gradually diminished to re-establish the desired phase-relation.

The receiver is coupled to the centre of the antenna line as shown, giving a bi-directional effect. The far ends may be free or grounded. In the former case the total length is an integral odd multiple of half a "wire" wavelength, whilst in the latter it is an integral even multiple. Alternatively a multiple-section antenna may be folded



(a)



(b)

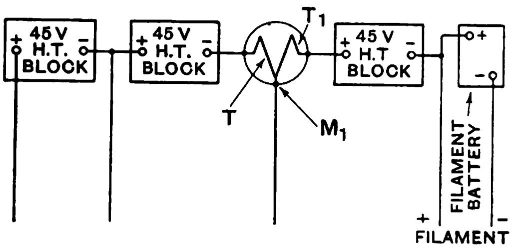
back on itself as shown in (*b*) thus avoiding the necessity of making any ground connection.

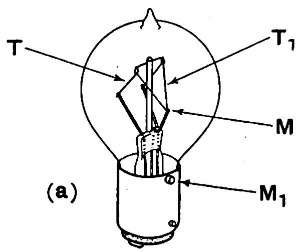
In this arrangement the system is non-directional, and the spacing of adjacent verticals is made an integral multiple of one-quarter the signal wavelength. The surge impedance network *N* absorbs end-reflection effects.

SAFETY DEVICE FOR VALVE SETS.

(*Convention date* (*U.S.A.*), 13*th May*, 1925. *No.* 252,181.)

The resistance of a tungsten wire filament in an atmosphere of hydrogen is comparatively low at normal operating temperatures, but rises automatically to a high value when the filament current exceeds a certain critical value.





The British Thomson-Houston Co. utilises this property to provide a safeguard against damage due to accidental short-circuiting in a multivalve receiver. The safety lamp is inserted between two of the H.T. supply units, so that one-half T_1 of the tungsten filament is inserted between the 45 volt lead to the detector plate and the low tension supply, whilst the other half T lies between the 135-volt lead to the last amplifier and that carrying the detector plate voltage. A short-circuit between the 135-volt lead and the filament supply therefore includes both limbs T and T_1 of the safety filament in series.

The mid-point M of the filament is taken to an external terminal M_1 on the lamp holder as shown. In this way any dangerous rush of current is automatically prevented, and valve filaments and transformer windings are safeguarded. Incidentally the glowing of the tungsten wire gives a visible warning to disconnect the H.T. batteries before they are badly damaged.

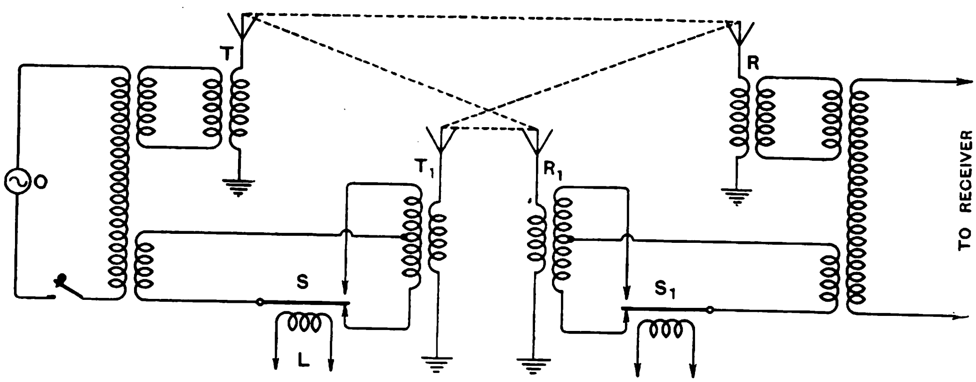
PREVENTING FADING.

(*Convention date* (*U.S.A.*), 2*nd January*, 1926. *No.* 263,876.)

As the result of observations it is found that short-wave signals will sometimes "fade" differently at points separated by no more than 500 feet. The effect is more pronounced with greater distances, and in the case of receiving aerials separated by several miles, it becomes quite common. In such cases it is noticed that the phase-relationship of the waves between the points in question will reverse several times a minute.

This affords a clue to the method now suggested by the Marconi Co. as a means of eliminating or minimising fading in short-wave signalling systems. In brief, it consists in combining the signals received on two or more separated aerials in such a way as to be independent of the signal phase in space. If, for instance, the phase relationship is maintained, then fortuitous reversals may give a "null" effect in the combined receiving circuit even if signal voltages do in fact exist in each of the separated aerials. On the other hand, by removing any fixed phase-relationship, signals will be heard in the common detector circuit so long as any signal voltage is being induced in either aerial.

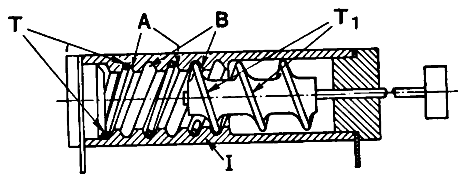
The figure illustrates an arrangement in which a periodical phase reversal is introduced both at the transmitting and receiving ends. Of the two transmitting aerials T, T_1, the first is coupled to the high-frequency source O in the ordinary way, whilst the second is connected through a tapped coil, the upper and lower segments of which are alternately brought into circuit by means of a switch S operated from a 60-cycle source. A similar switching arrangement S_1 is used in connection with the distant receiving aerials R, R_1, both of which feed the common receiver circuit shown.



SMALL CAPACITY CONDENSERS.

(*Application date, 27th January,* 1926. *No.* 271,920.)

Relates to small variable condensers of the type used for neutralising or balancing high-frequency amplifiers. The two interacting capacity elements are helical in form and are arranged to have a variable degree of overlap.

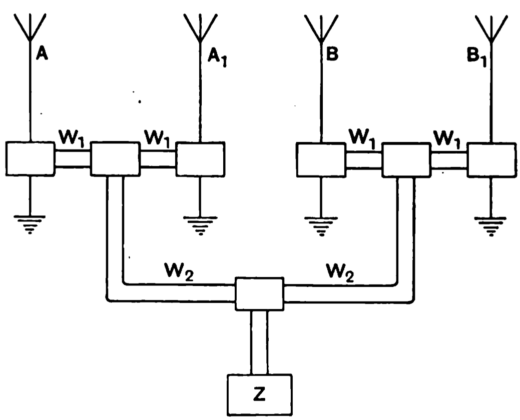


The first element T is a metal helix running from one end of an insulating tube or holder I in a set of spiral grooves A. The other element T_1 takes the form of a worm moving to and fro in a second set of parallel grooves B. Both the elements are substantially circular in cross-section. The tube I may have a screwed end-piece for mounting in a panel, or both ends may be pointed to fit into a clip-holder. Patent issued to B. Hesketh.

AERIAL COUPLING SYSTEMS.

(*Application date, 27th February,* 1926. *No.* 271,577.)

The energy received upon one or more pairs of aerials A, A_1 and B, B_1 is rendered cumulative for each pair of intermediate feeders W_1, the currents in these being again combined vectorially

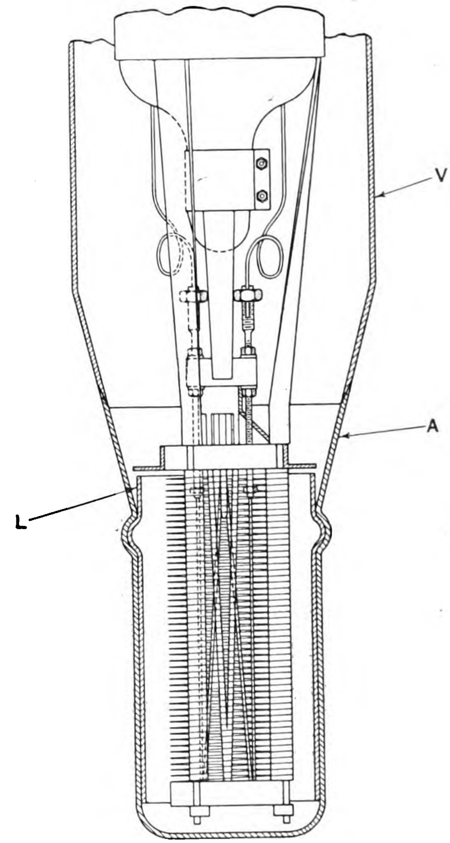


in feeders W_2, until finally collected in a terminal tank circuit Z which is connected across the input of the receiving set. The system is shown to be equivalent to a balanced three-wire circuit with the neutral wire removed. By this arrangement maximum transference of energy either from the aerial to a receiver, or from a source of power to a transmitting system, is ensured, when the various impedances are suitably matched. Patent granted to G. A. Mathieu.

THERMIONIC-POWER GENERATORS.

(*Application date, 5th March,* 1926. *No.* 271,960.)

Thermionic generators of the water-cooled anode type, as used for high-powered transmission, are liable to be seriously damaged by any sudden rush of current due, for instance, to some disturbance in the power supply or oscillatory circuits.



According to this invention, the Standard Telephones and Cables Co. provide a lining L of a refractory material such as molybdenum, to the metal anode A, which is sealed as usual to the vitreous bulb or envelope V. The molybdenum may be contiguous with the anode as shown, or may be separated from it by spacers, the intervening zone being evacuated. The lining serves to prevent the formation of local " hot spots " on the copper anode, which give rise to excessive production of vapour and consequent rupturing of the valve by arcing.

EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

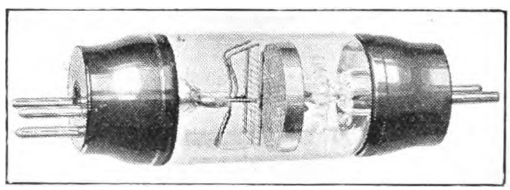
VOL. IV. NOVEMBER, 1927. No. 50.

Editorial.

The National Radio Exhibition, Olympia, 1927.

IN our October issue we promised to deal individually with some of the outstanding features of the Exhibition. There was general agreement that it was a very successful exhibition from every point of view, although, as on previous occasions, one felt the unavoidable limitations due to the lack of any facilities for demonstrating loud-speakers in operation. This is very much to be regretted at the present time when so many people are ignorant of the advances which have been made in loud-speaker design, and still fancy that good quality can only be obtained on the headphones. Many exhibitors got over the difficulty to some extent by inviting visitors to show-rooms in the neighbourhood of Olympia where their loud-speakers and sets could be seen and heard in operation. It is certain, however, that the present arrangement is preferable to any half-hearted attempt to give demonstrations within the building; if done at all it would have to be done very well. After all, the radio exhibitor is in no worse position than the motor exhibitor, whose optimistic pronouncements as to speed and petrol consumption have to be tested elsewhere than in the Show.

The exhibit can undoubtedly be taken as a fair guide to the present tendencies in broadcast receiver design and operation. From this point of view one can safely say that crystal detectors and headphones are almost obsolete so far as the industry is concerned, that except in portable sets, the horn type of loud-speaker has been displaced by the large diaphragm type for domestic use; that a battle is being waged between the dry battery, the accumulator, and the mains supply unit as a source of anode current; that makers are realising the importance of metal linings and screens in the radio-frequency sections of cabinets, and that a feverish interest is being shown in new types of valves, especially those of the screened or shielded anode type with which we dealt in our last issue.

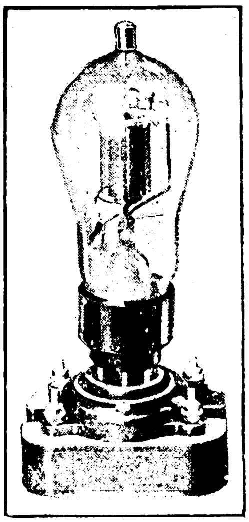


The Marconi and Osram type of screened anode valve.

With one or two exceptions the number of adjusting knobs on the front of the receiver has been reduced to a minimum. This is partly due to improvements in valve characteristics making it no longer necessary to adjust the filament currents individually or even at all; it is partly due to the development of the unified or "gang" control of two or more condensers, making it possible to tune all the high frequency circuits

simultaneously. This is such an important advantage to the ordinary user that one is justified in sacrificing some amplification to obtain such simplicity in manipulation.

With reference to the question of anode current supply there is the same choice between the troublesome technical ideal as represented by the absolutely steady and low resistance wet battery, either primary or secondary, the dry battery which in its larger sizes is almost ideal and free from trouble beyond the necessity of occasional renewal, and the mains unit which can be made to approach as near to the ideal as one is prepared to pay for in the way of reduction of resistance and increase of smoothing apparatus.



The B.T.H. screened valve.

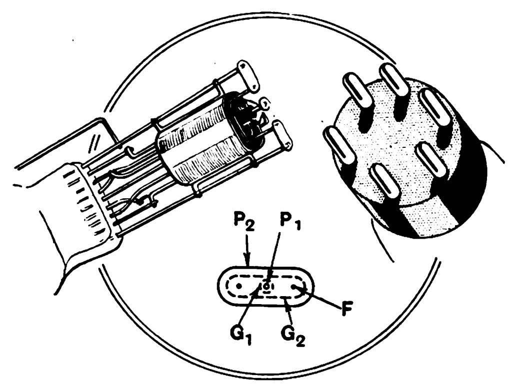
Mention should be made of the great number of portable sets exhibited, some of them of beautiful workmanship both inside and out ; but one would be more inclined to discuss them if they had been able to show the quality of their reproduction. Wonderful ingenuity had been shown in arranging a complete superheterodyne set together with all the batteries, frame aerials and loud-speaker within the compass of a small suit case.

The high standard of quality which was the outstanding general feature both of the sets and of the components was also noticeable in the ammeters and voltmeters which are now put forward for wireless work. The Ferranti Company showed a number of single and multi-range instruments mounted in moulded cases of insulating material of either the portable or flush pattern. These varied in price from 30s. to 55s., and would make a strong appeal to the serious experimenter.

We do not propose, however, to attempt any complete enumeration of the exhibits, as this has been done very fully by our contemporary, the *Wireless World*.* We must, however, describe in some detail two novel forms of valve each of which attracted a large amount of attention.

The Midgley-Ediswan One-Valve Loud-Speaker Set.

An interesting and important novelty was shown by the Ediswan Company. This was a one-valve set designed by Mr. A. H. Midgley which, it is claimed, will give excellent headphone reception of many foreign stations, loud-speaker reception up to 20 miles from a main station and up to 80 miles from Daventry. The valve, however, is not an ordinary one but a six-pin bulb containing two anodes and two grids ; that is, the bulb really contains two valves with a common filament. Its performance should, therefore, be compared with that of a two- or three-valve set seeing that the retail price of the new valve is 22s. 6d. The single filament will take little current, but with the new three-electrode valves taking only 0.075 ampere, this is not such an important point as the claim that the Midgley valve has an H.T. current consumption of about a third of that ordinarily necessary for equivalent loud-speaker results.



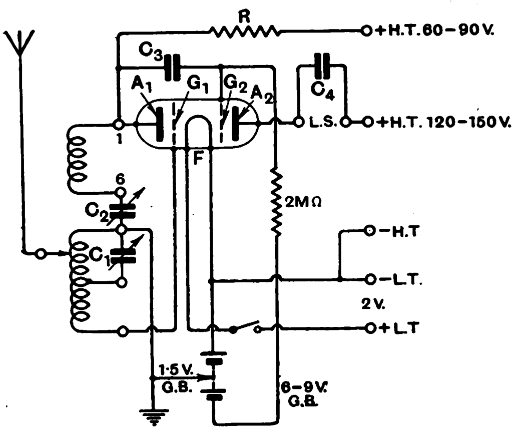
Details of the Midgley-Ediswan valve.

The electrode arrangement is cylindrical, the outer cylinder forming one anode and a central rod the other ; between them are the two cylindrical grids with the filament between them. The diagram of connections is reproduced.

The action appears to be somewhat as follows : The aerial-earth circuit is tuned

* *Wireless World*, 28th September and 5th October.

by means of the condenser C_1 and the voltage across C_1 is stepped up and applied to the grid G_1. The valve G_1A_1 probably acts as an anode-bend rectifier, the high-frequency component of the anode current passing through the reaction coil 1—6 and



Circuit of the Ediswan receiver.

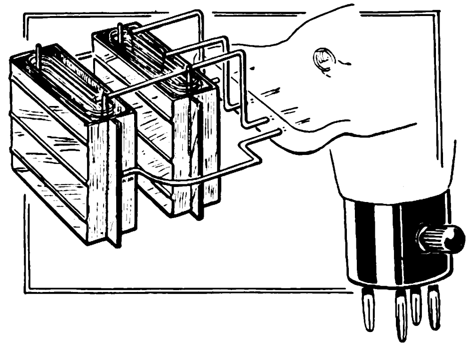
the condenser C_2, while the audio-frequency component passing through the resistance R, affects the potential of G_2 through the condenser C_3. In other words, the valve G_1A_1 is resistance-capacity coupled to the valve G_2A_2. The condenser C_4 shown in parallel with the loud-speaker is probably necessary to bypass the radio-frequency currents due to the effect of the radio grid G_1 on the emission from the filament to A_2.

It is claimed that the set does not re-radiate, presumably owing to the coupling being fixed at a point below the oscillation limit.

It will be interesting to compare the performance of the set with that of two ordinary valves in the same circuit; this will be an easy matter as the Ediswan Co. propose to supply the components to enable amateurs to build Midgley sets.

The Robinson-R.I. and Varley Interdyne.

Considerable interest was aroused by a set exhibited by the R.I.-Varley Co., in which a new type of valve was employed. This valve, to which the name Interdyne has been given, is due to Dr. J. Robinson. In the ordinary valve the capacity between the anode and grid necessitates the use of an external neutralising condenser to counterbalance the reaction and consequent tendency to oscillation. Dr. Robinson conceived the idea of placing the neutralising condenser inside the bulb of the valve and, moreover, of making it a replica of the anode-grid element the capacity of which it is intended to counterbalance. In addition to the working anode and grid, the interdyne valve has thus a dummy anode and grid. It is claimed that better results are thereby obtained. It would be interesting to try to utilise burnt out valves as neutralising condensers to valves of the same type. One drawback



Arrangement of the Robinson-R.I. and Varley valve.

in each case as compared with the usual type of neutralising condenser is the impossibility of adjustment if the neutralisation is not exact; it is quite possible, however, that the absence of adjustment may be regarded as one of the main advantages of the new device.

Some Notes on the Effect of Coupling between Loop and Beating Oscillator Circuits in a Superheterodyne Receiver.

By E. H. Ullrich, M.A., A.M.I.E.E., and

A. H. Reeves, A.C.G.I., D.I.C.

(*International Standard Electric Corporation.*)

WHEN the beating oscillator and loop circuits of a superheterodyne are coupled to the grid of the first detector valve in any of the more common ways, there usually exists a certain degree of coupling between the beating oscillator and loop circuits themselves. Fig. 1 gives a circuit diagram in which the beating oscillator voltage is introduced inductively. The direct consequence of this coupling is

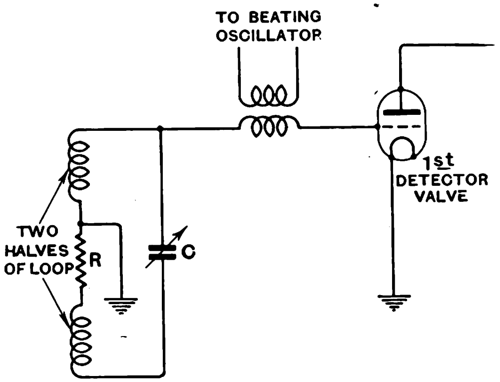


Fig. 1.

that the tuning of either circuit affects the other, the degree of inconvenience caused depending on the frequency to be received and the frequency of the intermediate amplification. In the ordinary broadcasting range the trouble is not a serious one, but at wavelengths less than 100 metres it becomes very difficult to tune in a signal properly, unless the intermediate frequency is raised considerably above 100 kilocycles with consequent loss of amplification, selectivity and stability. If the tuning process followed is that of varying the oscillator condenser setting until the signals in the headphones are of maximum loudness and then varying the loop tuning until a further maximum is obtained, it is found that the same station may be tuned in at different times on widely different settings of both loop and oscillator condensers. Furthermore, with values of coupling usual at less than 100 metres the frequency of the beating oscillator is a discontinuous function of both tuning condensers; in other words, as the latter is increased, there will be a point at which an infinitesimally small change of capacity causes a finite frequency change. In addition there is the hysteresis effect, well known in connection with coupled oscillator circuits. The trouble may be mitigated by reducing the coupling of the beating oscillator to the grid circuit of the detector, but this will lower the beating oscillator voltage on the detector and thereby cut down the signal in the headphones; the advantage gained hardly warrants the sacrifice in amplification.

The sudden change of frequency, which may be caused by variation of tuning of a secondary circuit, has been investigated by several people.* The writers, however, do not know of any published discussion of the precise circuit involved here and feel that a short mathematical investigation may be of interest.

Let us consider Fig. 2, in which the beating oscillator voltage is introduced on to the grid of the detector by means of a small coil of inductance L_2 and mutual inductance M_2 with the inductance in the oscillatory circuit of the oscillator. For simplicity we shall treat the impedance of L_2 as negligible

* Rogowski. *Die Frequenzsprünge des Zwischenkreisröhrensenders Arch. f. Elektrot,* 10, 1 (1921), etc.

compared with the impedance at beating oscillator frequency of the loop circuit $L_3 R_3 C_3$.

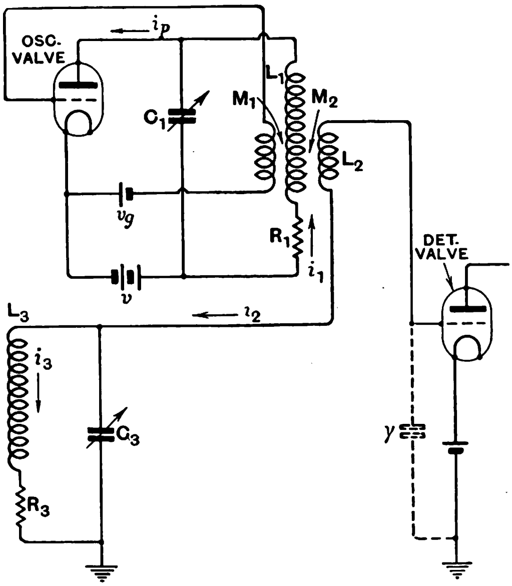


Fig. 2.

Attaching the usual meanings to the symbols used, we have the equations :—

$$e_p = V - \int\frac{(i_p - i_1)dt}{C_1} \qquad \ldots \quad (1)$$

$$\int\frac{(i_p - i_1)\,dt}{C_1} = R_1 i_1 + L_1\frac{di_1}{dt} - M_2\frac{di_2}{dt} \qquad (2)$$

$$R_p i_p = e_p + \mu e_g = e_p - \mu\left(v_g + M_1\frac{di_1}{dt}\right) \qquad (3)$$

whence we get

$$R_p\left[i_1 + C_1R_1\frac{di_1}{dt} + C_1L_1\frac{d^2i_1}{dt^2} - C_1M_2\frac{d^2i_2}{dt^2}\right]$$
$$= V - \mu v_g - \left(R_1i_1 + L_1\frac{di_1}{dt} - M_2\frac{di_2}{dt}\right) - \mu M_1\frac{di_1}{dt} \qquad (4)$$

We have also

$$M_2\frac{di_1}{dt} = L_3\frac{di_3}{dt} + i_3R_3 + \int\frac{i_2dt}{\gamma} \qquad (5)$$

$$L_3\frac{di_3}{dt} + R_3i_3 = \int\frac{(i_2 - i_3)\,dt}{C_3} \qquad \ldots \quad (6)$$

whence we get the equation—

$$-R_pC_1M_2^2C_3L_3\frac{d^6i_3}{dt^6}$$
$$-(R_pC_1M_2^2C_3R_3 + M_2^2C_3L_3)\frac{d^5i_3}{dt^5}$$
$$+\left\{-M_2^2C_3R_3 - M_2^2R_pC_1 + C_1L_1R_p\left(L_3 + \frac{C_3L_3}{\gamma}\right)\right\}\frac{d^4i_3}{dt^4}$$
$$+\left\{-M_2^2 + C_1L_1R_p\left(R_3 + \frac{C_3R_3}{\gamma}\right) + \left(L_3 + \frac{C_3L_3}{\gamma}\right)\left(C_1R_1R_p + L_1 + \mu M_1\right)\right\}\frac{d^3i_3}{dt^3}$$
$$+\left\{\frac{C_1L_1R_p}{\gamma} + \left(R_3 + \frac{C_3R_3}{\gamma}\right)(C_1R_1R_p + L_1 + \mu M_1) + \left(L_3 + \frac{C_3L_3}{\gamma}\right)(R_1 + R_p)\right\}\frac{d^2i_3}{dt^2}$$
$$+\left\{\frac{1}{\gamma}(C_1R_1R_p + L_1 + \mu M_1) + (R_p + R_1)\left(R_3 + \frac{C_3R_3}{\gamma}\right)\right\}\frac{di_3}{dt}$$
$$+\frac{(R_p + R_1)}{\gamma}i_3 = 0 \qquad \ldots \quad (7)$$

The solutions of this equation are given by an algebraic equation of the sixth degree, which may be rearranged as follows :—

$$\left[x^2 + x\left\{\frac{R_1}{L_1} + \frac{(L_1 + \mu M_1)}{C_1R_pL_1}\right\} + \frac{(R_p + R_1)}{C_1R_pL_1}\right]\left[x^2 + \frac{R_3}{L_3}x + \frac{1}{L_3(C_3 + \gamma)}\right]$$
$$-\frac{M_2^2C_3}{L_1\left(1 + \frac{C_3}{\gamma}\right)}\left[x^6 + \left(\frac{R_3}{L_3} + \frac{1}{R_pC_1}\right)x^5 + \left(\frac{R_3}{L_3}\cdot\frac{1}{R_pC_1} + \frac{1}{C_3L_3}\right)x^4 + \frac{x^3}{R_pC_1C_3L_3}\right] = 0 \qquad (8)$$

In the case where M_2 is zero the solution of equation (7) is very closely—

$$i_3 = Ae^{-\frac{1}{2}\left\{\frac{R_1}{L_1} + \frac{(L_1 + \mu M_1)}{C_1R_1L_1}\right\}t}\sin\left(\frac{t}{\sqrt{L_1C_1}} + \epsilon_1\right)$$
$$+ Be^{-\frac{R_3t}{2L_3}}\sin\left(\frac{t}{\sqrt{L_3(C_3 + \gamma)}} + \epsilon_2\right) \qquad (9)$$

where A, B, ϵ_1 and ϵ_2 are arbitrary constants.

The frequencies correspond to the natural frequencies of the simple loop and oscillator circuits, and the oscillation due to the loop circuit dies away at once. The oscillation due to the beating oscillator circuit will build up, if M_1 is negative and sufficiently large. When, however, the strength of oscillation is greater than can be handled

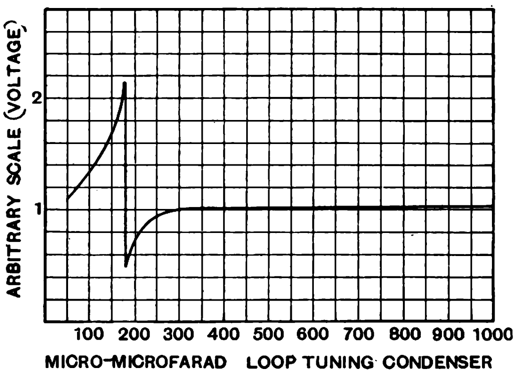


Fig. 3.

by the straight part of the valve characteristic, R_p and μ change to new average values such that

$$\frac{R_1}{L_1} + \frac{(L_1 + \mu M_1)}{C_1 R_p L_1} = 0$$

The effect of the presence of a small M_2 is to change slightly the two theoretical frequencies of oscillation and to change their decrements. We may write in this case

$$i_3 = Ae^{-a_1 t} \sin\,(\omega_1' t + \epsilon_1) + Be^{-a_3 t} \sin\,\omega_3' t + \epsilon_3) \qquad (10)$$

where ω_1' is approximately

$$\frac{1}{\sqrt{L_1 C_1}}$$

and ω_3' is approximately

$$\frac{1}{\sqrt{L_3(C_3 + \gamma)}}$$

The decrement of the oscillation corresponding to the loop circuit is approximately

$$a_3 = \frac{R_3}{2L_3} - \frac{M_2^2 \gamma^2 \omega_3^3 \delta_3}{2L_1(C_3 + \gamma)\,(4\epsilon^2 + \delta_3^2)} \qquad (11)$$

where
$$\omega_1 \equiv \frac{1}{\sqrt{L_1 C_1}}$$
$$\omega_3 \equiv \frac{1}{\sqrt{L_3(C_3+\gamma)}}$$
$$\omega_3 \equiv \omega_1(1-\epsilon)$$
and
$$\delta_3 \equiv R_3/\omega_3 L_3$$

If $\epsilon > \delta_3$, this is approximately

$$a_3 = \frac{\omega_3\delta_3}{2} - \frac{M_2^2\gamma^2\omega_3^5\delta_3}{8\epsilon^2} \times \frac{L_3}{L_1} \quad \ldots \quad (12)$$

If ϵ is reduced until a_3 just becomes negative, the frequency changes suddenly from ω_1' to ω_3'.

The critical value of ϵ is given by $a_3 = 0$; whence

$$\epsilon_c = \pm \frac{M_2\gamma\omega_3^2}{2}\sqrt{\frac{L_3}{L_1}} \quad \ldots \quad (13)$$

From (11) it will be seen that a_3 cannot become negative unless

$$M_2 > \frac{\delta_3}{\gamma\omega_3^2}\sqrt{\frac{L_1}{L_3}}$$

Let us consider the effect on a_3 of raising the frequency limits of the system, *e.g.*, changing from a set for broadcasting wavelengths to one operating between 10 and 100 metres.

If the oscillator is oscillating powerfully the voltage on the plate will fall to a low

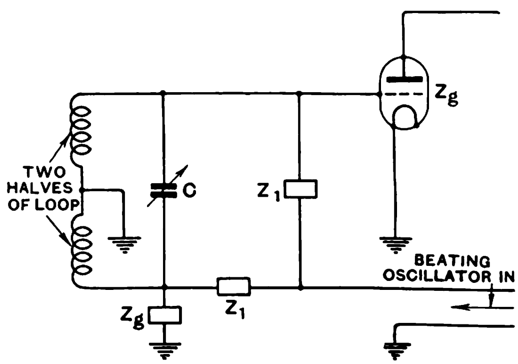


Fig. 4.

value, *i.e.*, the voltage across L_1R_1 will depend chiefly on the plate battery. Now the volts picked up in L_2 will depend chiefly on the requirements of the detector tube, *i.e.*, will be practically independent of

frequency; and the ratio of this voltage to the voltage across L_1R_1 is very nearly M_2/L_1. Actually, however, the tendency is for oscillators to oscillate less powerfully at the shorter wavelengths, so that M_2/L_1 tends to increase somewhat with frequency; *i.e.*, $M_2C_1\omega_1^2$ tends to increase with frequency. γ is constant and C_1 and C_3 are

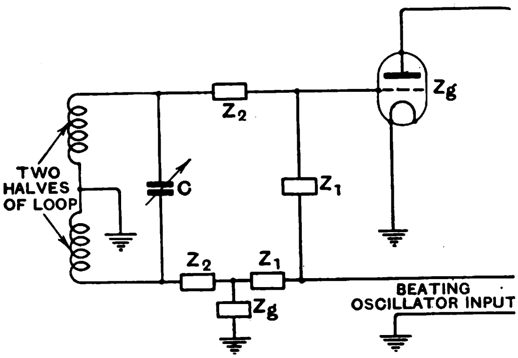


Fig. 5.

variable condensers, which cannot be conveniently reduced much below $100\mu\mu F$ maximum capacity, whatever the frequency limits of the receiver. Therefore $M_2\omega_1^2$ and also $M_2\omega_3^2$ tend to increase with frequency. L_1 and L_3 must be chosen so that they can be made to resonate with C_1 and C_3 respectively at the lower frequency limit. They will naturally be approximately equal. Therefore from (13) ϵ_c tends somewhat to increase as the frequency limits of the system are raised.

In consequence of this it follows that, if the frequency limits of a superheterodyne receiver are multiplied by a factor "p" the difficulties due to the coupling between loop and beating oscillator circuits will be increased, unless either the intermediate frequency is multiplied by a factor somewhat greater than "p," or precautions are taken to prevent the tuning of the loop circuit from affecting the beating oscillator frequency.

In Fig. 4 a means of introducing the beating oscillator voltage on to the grid of the first detector is shown, wherein one point, at high beating oscillator potential to earth, is coupled through two equal impedances Z_1 to the extremities of the loop tuning condenser C. From the symmetry of the system it will be seen that no beating oscillator voltage will exist across condenser C, so that the tuning of the loop cannot affect the beating oscillator circuit. In other words, the coupling between the two circuits is nil. It will be seen, however, that in this case the currents flowing in the two halves of the loop are equal and opposite, and consequently, the inductance of each half of the loop will be practically zero to the beating oscillator current. In other words, from the point of view of the beating oscillator, the grid of the first detector is practically short-circuited to earth, so that no beating oscillator voltage will be impressed upon the grid. It is, therefore, necessary to introduce two equal impedances Z_2, as shown in Fig. 5. Although the impedances Z_1 and Z_2 may be of any nature, they will introduce undesirable losses if they contain large resistive components. The circuit of Fig. 6 is, therefore, particularly applicable, the 100,000-ohm leak across condenser D being introduced to stabilise the grid bias, and condenser F having the same value as condensers D and E in series. The presence of the leak across condenser D and the omission of impedance Z_g do not cause any appreciable disturbance of balance of the system. The degree of independence

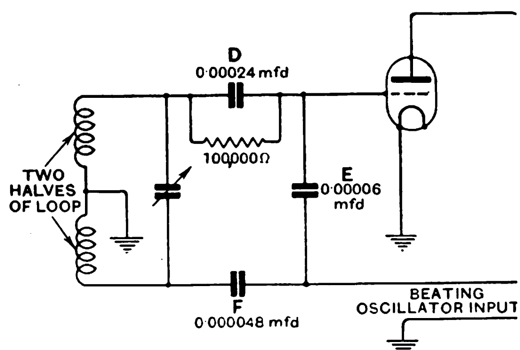


Fig. 6.

of the loop and beating oscillator circuits may be tested by noting the variation of the plate current of the first detector, when the beating oscillator is working and the loop tuning condenser is being slowly turned. When this experiment was carried out at 200 metres, no variation whatever of the plate current was observed, showing that a very

high degree of balance had been obtained. At 50 metres the grid-to-plate capacity of the tube had a very appreciable disturbing effect and had to be compensated for by a small condenser between plate and one side of the loop, as seen in Fig. 7, and the condenser corresponding to *F* in Fig. 6 was made variable to secure an accurate balance.

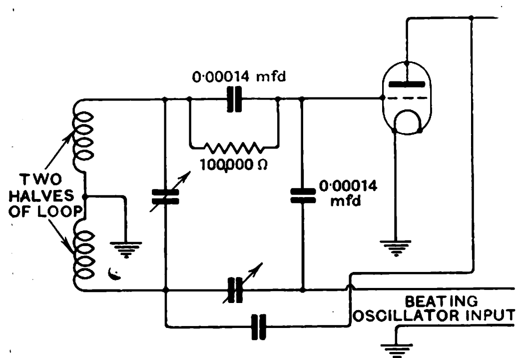


Fig. 7.

The variation of grid-filament volts at beating oscillator frequency, as indicated by the change of plate current as the loop circuit was varied through the point of resonance to the beating oscillator, was then easily reduced to less than $\pm\frac{1}{2}$ per cent. In Fig. 3 the beating oscillator voltage between grid and filament of the detector valve has been plotted against loop tuning condenser for the circuit of Fig. 1. We have assumed—

a beating oscillator frequency of 1,050,000 cycles ;

a loop inductance of 0.1265 millihenries (giving resonance with 200$\mu\mu$F) ;

a loop resistance of 20 ohms ; and

a grid-to-filament capacity of 30$\mu\mu$F (this including the capacity to earth of the coupling coil of negligible inductance).

The grid-filament beating oscillator voltage is seen to change by 300 per cent. as the loop tuning is varied. It must be remembered, also, that if the loop resistance had been 10 instead of 20 ohms, the maximum and minimum beating oscillator volts in Fig. 3 would have been doubled and halved respectively, so that the variation would have been 1,500 per cent.

The effect of the three condensers *D*, *E* and *F* in Fig. 6 is to increase the minimum capacity across the loop by 0.000024μF and to reduce the signal voltage that reaches the grid by 20 per cent. Without the device, however, the sensitivity is very considerably more than 20 per cent. below the maximum at 100 metres, as the beating oscillator coupling must be kept very low in order to avoid the disturbing effects mentioned above. The beating oscillator voltage on the detector grid is in consequence very small.

Theory of Receiving Aerials.

By F. M. Colebrook, B.Sc., D.I.C., A.C.G.I.

THE writer received some time ago a copy of a very interesting paper by Mr. E. B. Moullin, "On the Current Induced in a Wireless Telegraph Receiving Antenna." The following article is an extension of the above admirable introduction to a somewhat neglected subject. The writer wishes to make the fullest possible acknowledgments to Mr. Moullin, and does not claim to have done anything more than generalise the original work and to have emphasised certain conclusions which, though implicit in Mr. Moullin's work, were not specifically stated.

It so happened that the writer was actually engaged on the problem at the time he received the paper referred to, with the object of answering the following questions :—

1. What is the nature of the effective impedance of a receiving aerial from the point of view of associated receiving apparatus ?

2. Is the effective impedance dependent on (*a*) the nature of the tuning or receiving circuit ; (*b*) the distribution of the electric field due to the signal ?

3. What part is played by the distributed resistance of an aerial ?

4. What is the effective height of an aerial, and does it depend on (*a*) the tuning circuit conditions ; (*b*) the field distribution ?

5. Is there any optimum distribution for a given length of aerial ?

The problem had been tackled on rather different lines from Mr. Moullin's, and unsuccessfully, owing to a mishandling of the mathematics involved. The application of Mr. Moullin's method led to the solution of these questions, and as a result of the familiarity with the subject so gained the writer has since found that his original method, properly handled, is equally effective and leads to the same conclusions.

Analysis is apt to be dullish reading. The writer will therefore content himself with presenting the merest outline of the work, just sufficient to enable anyone sufficiently enthusiastic to check it for himself.

The physical conditions of the problem and the more important symbols are represented in Fig. 1. The current co-ordinates x_1 and x_2 follow the actual lines of the vertical and horizontal parts of the aerial structure. It is assumed that each part of the aerial has a certain resistance (including radiation resistance), inductance and capacity per unit length, these being uniform in each part. This may not be strictly true, as proximity to the ground may cause a local variation of capacity. This is not likely to be very pronounced, however, and will be referred to later.

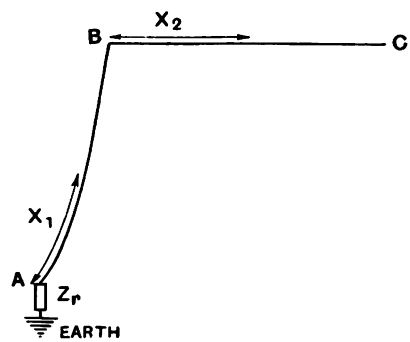


Fig. 1.

In most cases of distant reception the field due to the signal will probably be sensibly uniform over the space occupied by the aerial. The aerial itself, however, is not a geometrical design drawn on paper, but a number of wires hung up in space in some convenient way. In general, therefore, it will not be symmetrically disposed with regard to the field, and the E.M.F. induced per unit length may be far from uniform. This has been taken into account by representing the field intensities as $f_1 (x_1)$ and $f_2 (x_2)$ respectively for the vertical and horizontal parts of the aerial, *i.e.*, the E.M.F. induced in an element dx_1 will be $f_1 (x_1) dx_1$. The top part of the aerial is shown as a single line, for the sake of simplicity. It may, of course, consist of more than one line but this does not affect the state of affairs provided the lines run parallel and are not widely separated compared with their length.

Considering the vertical part first, the differential equations for $\mathbf{v}_1$ and $\mathbf{i}_1$ will be

$$(R_1 + j\omega L_1)\mathbf{i}_1 - \mathbf{e}_1 = -\partial \mathbf{v}_1/\partial x_1 \quad \ldots \quad (1)$$

$$j\omega C_1 \mathbf{v}_1 = -\partial \mathbf{i}_1/\partial x_1 \quad \ldots \quad (2)$$

where

$$\mathbf{e}_1 = f_1(x_1) \quad \ldots \quad (3)$$

Here $\mathbf{v}_1$ and $\mathbf{i}_1$ are vectors representing the potential with respect to earth and the current respectively, and $\omega/2\pi$ is the frequency of the signal E.M.F., assumed to be a pure continuous wave for the sake of simplicity. These equations are essentially the same as those used by Mr. Moullin, except that R_1 is introduced and $\mathbf{e}_1$ is not regarded as independent of x_1.

The differentiation of these equations with respect to x_1 gives two more, *i.e.*,

$$P_1^2 \mathbf{i}_1 - j\omega C_1 \mathbf{e}_1 = \partial^2 \mathbf{i}_1/\partial x_1^2 \quad \ldots \quad (4)$$

$$P_1^2 \mathbf{v}_1 + \partial \mathbf{e}_1/\partial x_1 = \partial^2 \mathbf{v}_1/\partial x_1^2 \quad \ldots \quad (5)$$

where

$$P_1^2 = (R_1 + j\omega L_1)\, j\omega C_1 \quad \ldots \quad (6)$$

It will be found that the solutions of these equations are

$$\mathbf{i}_1 = \mathbf{A}_1 \sinh P_1 x_1 + \mathbf{B}_1 \cosh P_1 x_1 + \psi_1(x_1) \quad (7)$$

$$\mathbf{v}_1 = -Z_1(\mathbf{A}_1 \cosh P_1 x_1 + \mathbf{B}_1 \sinh P_1 x_1) - \phi_1(x_1) \quad (8)$$

where

$$\psi_1(x_1) = j\omega C_1 \frac{\mathbf{e}_1}{P_1^2 - D^2} \quad \ldots \quad (9)$$

(D being written for the operation $\partial/\partial x$)

$$\phi_1(x_1) = \frac{1}{j\omega C_1} \frac{\partial \psi_1(x_1)}{dx_1} \quad \ldots \quad (10)$$

$$Z_1^2 = \frac{R_1 + j\omega L_1}{j\omega C_1} \quad \ldots \quad (11)$$

It should be noted that the constants P_1 and Z_1 depend only on the aerial, while the functions of x_1 depend on the constants of the aerial and the field distribution. The quantities $\mathbf{A}_1$ and $\mathbf{B}_1$ are constant vectors, in the same way that $\mathbf{i}_1$ and $\mathbf{v}_1$ are vectors.

This may seem rather heavy going for the not very mathematical reader, but the worst is over. The calculus is finished with at this point, and nothing more is required than a nodding acquaintance with $(a+jb)$ quantities, hyperbolic functions and elementary algebra.*

* See "Alternating Currents and Transients." Colebrook. (McGraw-Hill.)

The equations for the horizontal part will obviously be of the same form as for the vertical part, so we have finally

$$\mathbf{i}_1 = \mathbf{A}_1 \sinh P_1 x_1 + \mathbf{B}_1 \cosh P_1 x_1 + \psi_1(x) \quad (12)$$

$$\mathbf{v}_1 = -Z_1(\mathbf{B}_1 \sinh P_1 x_1 + \mathbf{A}_1 \cosh P_1 x_1) - \phi_1(x_1) \quad (13)$$

$$\mathbf{i}_2 = \mathbf{A}_2 \sinh P_2 x_2 + \mathbf{B}_2 \cosh P_2 x_2 + \psi_2(x_2) \quad (14)$$

$$\mathbf{v}_2 = -Z_2(\mathbf{B}_2 \sinh P_2 x_2 + \mathbf{A}_2 \cosh P_2 x_2) - \phi_2(x_2) \quad (15)$$

There appear to be four unknown constant vectors in these equations, but there are in fact only two, for they are not independent. At the point $x_1 = h_1$, $x_2 = 0$ we have $\mathbf{i}_1 = \mathbf{i}_2$ and $\mathbf{v}_1 = \mathbf{v}_2$, therefore

$$\mathbf{A}_1 \sinh P_1 h_1 + \mathbf{B}_1 \cosh P_1 h_1 + \psi_1(h_1) = \mathbf{B}_2 + \psi_2(0) \quad (16)$$

$$Z_1(\mathbf{A}_1 \cosh P_1 h_1 + \mathbf{B}_1 \sinh P_1 h_1 - \phi_1(h_1)) = Z_2 \mathbf{A}_2 - \phi_2(0) \quad (17)$$

so that $\mathbf{B}_2$ and $\mathbf{A}_2$ can be expressed in terms of $\mathbf{A}_1$ and $\mathbf{B}_1$. In addition there are two boundary conditions. At the foot of the aerial we have the tuning impedance $Z_r = R_r + jX_r$. Putting $\mathbf{i}_r$ and $\mathbf{v}_r$ for the current in the tuning impedance and the potential difference across it, then since $x_1 = 0$

$$\mathbf{i}_r = \mathbf{B}_1 + \psi_1(0) \quad \ldots \quad \ldots \quad (18)$$

$$\mathbf{v}_r = -Z_1 \mathbf{A}_1 - \phi_1(0) \quad \ldots \quad (19)$$

Therefore

$$\mathbf{A}_1 Z_1 + \phi_1(0) = \mathbf{B}_1 Z_r + \psi_1(0) Z_r \quad \ldots \quad (20)$$

Further, when $x_2 = h_2$, $\mathbf{i}_2 = 0$, that is

$$\mathbf{A}_2 \sinh P_2 h_2 + \mathbf{B}_2 \cosh P_2 h_2 + \psi_2(h_2) = 0 \quad (21)$$

From the four equations (16), (17), (20), and (21) it is simple algebra to determine $\mathbf{A}_1$ and $\mathbf{B}_1$, and then, from equation (18), to determine $\mathbf{i}_r$. This step need not be given in detail. The result is

$$\mathbf{i}_r = \frac{\phi_1(0) + \frac{N}{M} Z_1 \psi_1(0) - \frac{Q}{M} Z_1}{Z_r + \frac{N}{M} Z_1} \quad (22)$$

where tho following abbreviations have been used.

$$M = Z_2 \sinh P_1 h_1 \cosh P_2 h_2 + Z_r \cosh P_1 h_1 \sinh P_2 h_2 \quad (23)$$

$$N = Z_2 \cosh P_1 h_1 \cosh P_2 h_2 + Z_1 \sinh P_1 h_1 \sinh P_2 h_2 \quad (24)$$

$$Q = Z_2 \psi_2(h_2) + K_2 Z_2 \cosh P_2 h_2 + K_1 Z_1 \sinh P_2 h_2 \quad (25)$$

$$K_1 = \phi_1(h_1) - \phi_2(0) \quad \ldots \quad \ldots \quad (26)$$

$$K_2 = \psi_1(h_1) - \psi_2(0) \quad \ldots \quad \ldots \quad (27)$$

These expressions may seem somewhat complicated, but the actual form of the result is very simple, for

$$\mathbf{i}_r = \frac{\mathbf{e}_e}{Z_e + Z_r} \quad \ldots \quad \ldots \quad (28)$$

where

$$Z_e = \frac{N}{M} Z_1 \quad \ldots \quad \ldots \quad (29)$$

and

$$\mathbf{e}_e = \phi_1(0) + Z_e\{\psi_1(0) - Q/N\} \quad \ldots \quad (30)$$

Conclusions from the Form of the General Solution.

A number of useful conclusions can be drawn from the above without any further analysis.

(*a*) The effective impedance Z_e depends only on the constants of the aerial, being independent of Z_r and of the form of the field.

(*b*) The effective E.M.F. depends on the constants of the aerial and on the distribution of the fields.

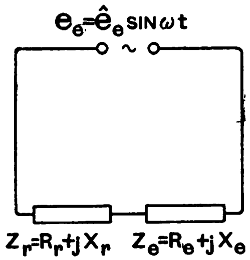


Fig. 2.

The complete circuit, consisting of the aerial with its distributed capacity, inductance and resistance and its distributed (not necessarily uniform) E.M.F.s and the tuning impedance, however constituted, can therefore be represented in the simple manner shown in Fig. 2, *i.e.*, as a simple series circuit. Of course, both the effective impedance of the aerial and the effective E.M.F. will vary with frequency in some more or less complicated manner to be considered later, but the simple equivalent quantities in Fig. 2 will accurately represent the state of affairs at any given frequency.

The effective height is clearly involved in the expression for the effective E.M.F. It should be noted that the effective height will depend on frequency, but will be independent of the tuning circuit.

Questions 1, 2 and 4 of the introduction have now been answered, at least in part, and the complete answers to the whole of the questions are contained in the above analysis.

Before considering the matter more in detail, however, one other point remains to be settled in relation to the general case. How does this reception of a distributed E.M.F. compare, from the point of view of the tuning or receiving circuit, with the behaviour of the aerial with respect to an E.M.F. concentrated at, say, the point $x_1 = 0$?

Considered as a special case of the general analysis, the solution can be obtained immediately by means of the appropriate substitutions, and the current through the tuning circuit impedance is given by

$$\mathbf{i}_r = \frac{\mathbf{e}}{Z_r + Z_e} \quad \ldots \quad \ldots \quad (31)$$

where Z_r and Z_e are as in the general case, and $\mathbf{e}$ is the vector representing the E.M.F. It may be thought that the substitution of a point E.M.F. for the continuous functions considered in the general case may not necessarily be legitimate. The writer has satisfied himself on this matter by retracing the steps of the analysis from the commencement. The conclusion is obviously consistent with the fact that the magnitude and distribution of the E.M.F. does not appear at all in the expression for the effective impedance.

This establishes a very useful fact, for it shows that, subject to the validity of the initial assumptions with regard to the general character of a receiving aerial, the effective aerial impedance and its variation with frequency can be studied experimentally by means of a local oscillator, with every assurance that the quantities so determined will be applicable to the behaviour of the aerial under any conditions of reception. The practical advantages of this are too obvious to need further comment.

Before considering the special cases and numerical quantities, further reference must be made to a point alluded to at the commencement of the analysis, *i.e.*, the possible non-uniformity of the capacity per unit length in the immediate neighbourhood of the earth connection.

The point has been considered in some

detail by Prof. Howe in his paper on the capacity of aerials.* He shows that the proximity effect is very local. It is nevertheless a matter for further investigation, and will be considered more fully at some future date. In any case, it is very unlikely that it will influence in any way the essential character of the results deduced, for even if the variation were so abrupt as to amount to a discontinuity, there is no reason to suppose that it would have any effect different in character from the discontinuity already considered at the junction between the vertical and horizontal parts of the aerial. Possibly the proximity effect could be exhibited as a small capacity permanently associated with the tuning circuit.

Further, some recent experiments carried out by Dr. Smith-Rose in conjunction with the present writer† have shown that a considerable part of the aerial resistance is associated with the earth connection, either as actual resistance or in the form of eddy current losses. This part of the total aerial resistance can be considered as permanently associated with the tuning circuit. Its effect will clearly be different from that of the distributed resistance to which the above analysis refers. This will not affect the analysis at all, beyond setting a limit beyond which the resistance of the tuning impedance cannot be reduced.

We are now in a position to consider certain important practical special cases, with a view to bringing the general solution into a more physically comprehensible form and, if possible, substituting actual quantities for some of the symbols.

1. If the component parts of the aerial are straight lines and the aerial is situated in a uniform (not necessarily vertical) field, then $\mathbf{e}_1$ and $\mathbf{e}_2$ are constants with respect to the current co-ordinates, so that

$$\psi_1(0) = \psi_1(h_1) = \mathbf{e}_1/P_1Z_1 \quad \ldots \quad (32)$$

$$\psi_2(0) = \psi_2(h_2) = \mathbf{e}_2/P_2Z_2 \quad \ldots \quad (33)$$

and

$$\phi_1(x_1) = \phi_2(x_2) = 0 \quad \ldots \quad \ldots \quad (34)$$

*"On the Capacity of Radio-Telegraphic Antennæ." Prof. G. W. O. Howe. *Wireless World*, Vol. II., pp. 546, 612, 680.

†"Some Experiments with Aerial and Earth Circuits." *E.W. & W.E.*, Vol. II., No. 16, p. 207, January, 1925.

The substitution of these values in the general solution will give

$$\mathbf{e}_e = \left[\frac{\mathbf{e}_1}{P_1Z_1} - \frac{1}{N}\left\{\frac{\mathbf{e}_2}{P_2} + Z\cosh Ph\left(\frac{\mathbf{e}_1}{P_1Z_1} - \frac{\mathbf{e}_2}{P_2Z_2}\right)\right\}\right]Z_e \quad (35)$$

and

$$Z_e = \frac{Z_1 + Z_2 \coth P_1h_1 \coth P_2h_2}{Z_1 \coth P_1h_1 + Z_2 \coth P_2h_2} \quad (36)$$

2. If, in addition, the aerial is uniform throughout in its electrical constants, *i.e.*, if both parts are composed of the same conductors similarly disposed or a single conductor, then we can put $Z_1 = Z_2 = Z$ and $P_1 = P_2 = P$, in which case the above expressions can be further reduced to

$$\mathbf{e}_e = \frac{1}{P}\,\frac{\mathbf{e}_1(\cosh Ph - \cosh Ph_2) + \mathbf{e}_2(\cosh Ph_2 - 1)}{\sinh Ph} \quad (37)$$

and $$Z_e = Z\coth Ph \quad \ldots \quad (38)$$

where $$h = h_1 + h_2 \quad \ldots \quad (39)$$

3. If the vertical and horizontal parts of the aerial are dissimilar, *i.e.*, have different constants, but the vertical part is parallel to a uniform field and the horizontal part perpendicular to it, then $\mathbf{e}_1 = \mathbf{e}$ and is constant with respect to x_1, while $\mathbf{e}_2 = 0$. Then

$$\mathbf{e}_e = \frac{\mathbf{e}}{P_1}\left\{\frac{Z_2\cosh P_2h_2(\cosh P_1h_1 - 1) - Z_1\sinh P_2h_2\sinh P_1h_1}{Z_2\sinh P_1h_1\cosh P_2h_2 - Z_1\cosh P_1h_1\sinh P_2h_2}\right\} \quad (40)$$

and Z_e will be the same as in case 1.

4. If in addition to the above the vertical and horizontal parts of the aerial have the same constants, then

$$\mathbf{e}_e = \frac{\cosh Ph - \cosh Ph_2}{\sinh Ph}\,\frac{\mathbf{e}}{P} \quad \ldots \quad (41)$$

and

$$Z_e = Z\coth Ph \quad \ldots \quad (42)$$

where $$h = h_1 + h_2$$

5. Finally, for the simplest case of all (scarcely ever seen outside a text-book), *i.e.*, a plain straight aerial parallel to a uniform vertical field, $\mathbf{e}_1 = \mathbf{e}$ (const.), $h_2 = 0$, giving

$$\mathbf{e}_e = \frac{\cosh Ph - 1}{\sinh Ph}\,\frac{\mathbf{e}}{P} \quad \ldots \quad (43)$$

$$= \frac{\mathbf{e}}{P}\tanh\frac{Ph}{2} \quad \ldots \quad (44)$$

and $$Z_e = Z\coth Ph \quad \ldots \quad (45)$$

Reduction of the Solutions to Scalar Form.

The foregoing expressions for the various special cases are not yet in a form suitable for numerical calculation, or for exhibiting the effect of the various constants of the aerial structure. For this purpose it will be necessary to reduce to the form $(a+jb)$ or $r\epsilon^{j\theta}$ the various complex functions of the aerial constants involved in the expressions for Z_e and $\mathbf{e}_e$.

This part of the work will be confined to the cases in which both parts of the aerial have the same electrical constants. The methods involved will be equally applicable to the general case, but the latter is so much more cumbersome in form that the main conclusions are likely to be obscured by the bulk of the expressions.

The following resolutions of Ph and Z into their component parts presents no difficulties.

$$P^2 = (R + j\omega L)\, j\omega C \quad \ldots \quad (46)$$

Therefore

$$(Ph)^2 = (Rh + j\omega Lh)\, j\omega Ch \quad \ldots \quad (47)$$

$$= (R_0 + j\omega L_0)\, j\omega C_0 \quad \ldots \quad (48)$$

where R_0, L_0, and C_0 are the total resistance, inductance and capacity of the aerial. If Ph be expressed in the form $A + jB$ (the A's and B's of the former part are now finished with, so no ambiguity will arise), then since

$$(A + jB)^2 = (R_0 + j\omega L_0)\, j\omega C_0 \quad \ldots \quad (49)$$

$$A^2 - B^2 = -\omega^2 L_0 C_0 \quad \ldots \quad (50)$$

$$AB = \omega C_0 R_0/2 \quad \ldots \quad (51)$$

whence

$$A^2 + B^2 = \omega C_0 \sqrt{R_0^2 + \omega^2 L_0} \quad (52)$$

On the assumption that $R_0^4/\omega^4 L_0^4$ is negligibly small compared with 1, the above equations will give for A and B

$$A = \frac{R_0}{2}\sqrt{\frac{C_0}{L_0}} \quad \ldots \quad \ldots \quad \ldots \quad (53)$$

$$B = \omega\sqrt{L_0 C_0}\left(1 + \frac{R}{8\omega^2 L_0^2}\right) \ldots \quad (54)$$

Also

$$Z = P/j\omega C \quad \ldots \quad \ldots \quad (55)$$

$$= Ph/(j\omega C_0) \quad \ldots \quad \ldots \quad (56)$$

$$= \frac{B}{\omega C_0} - j\frac{A}{\omega C_0} \quad \ldots \quad (57)$$

and substituting the values for A and B

$$Z = \sqrt{\frac{L_0}{C_0}}\left(1 + \frac{R_0^2}{B\omega^2 L_0^2}\right) - j\frac{R}{2}\sqrt{\frac{1}{\omega^2 L_0 C_0}} \quad (58)$$

Thus both Ph and Z are known in terms of the constants of the aerial.

It will now be well to consider a typical small receiving aerial in order to see what values these quantities may have in practice. We will assume the following dimensions :—

$$h_1 = 30 \text{ ft.} = 915 \text{ cms.}$$

$$h_2 = 70 \text{ ft.} = 2134 \text{ cms.}$$

$$h = h_1 + h_2 = 100 \text{ ft.} = 3049 \text{ cms.}$$

radius of wire = .108 cms. (abt. 3/19)

The inductance and capacity per unit length can be calculated from the formulæ

$$C = (4.606\, log_{10}(h/r) - .614)^{-1} \times 1.111 \ \mu\mu\text{F/cm.}$$

$$L = (4.606\, log_{10}(h/r) - .614)\ 10^{-9} \text{ H/cm.}$$

These will give

$$L = 19.887 \times 10^{-9} \text{ H/cm.} \quad L_0 = 60.64\mu\text{H.}$$

$$C = .056\ \mu\mu\text{F/cm.} \quad C_0 = 170.7\mu\mu\text{F.}$$

The resistance R_0 cannot very well be calculated, and very little data is available for an estimate. To be on the safe side in the matter of neglecting resistance terms in subsequent approximations, we will take $R_0 = 50$, which is likely to be a liberal estimate (it must be remembered that eddy current and earth connection losses are not included in this figure, these being considered as permanently associated with the tuning impedance).

From equations (61-63),

$$A = \frac{R}{2}\sqrt{\frac{C_0}{L_0}} \text{ (very approx.)}$$

$$= .042$$

In general A will be a small quantity, less than .1. The value of B will of course depend on the frequency at which the aerial is actually being used. Thus, for a wavelength of 365 metres,

$$B = \omega^2 L_0 C_0 \text{ (approx.)}$$

$$= .524.$$

It will be shown later that $B = 2\pi h/\lambda$ to a very close approximation, λ being the wavelength of operation.

We will now consider the resolution of the impedance expression into its resistance and reactance components.

$$Coth\ Ph = coth\,(A + jB) \ \ldots \quad \ldots \quad (59)$$

$$= \frac{sinh\ 2A - j\ sin\ 2B}{cosh\ 2A - cos\ 2B} \quad \ldots \quad (60)$$

and since

$$Z_e = Z \coth Ph \quad \ldots \quad \ldots \quad (61)$$

$$= \frac{1}{\omega C_0}(B - jA) \coth Ph \ldots \quad (62)$$

$$= R_e + jX_e \quad \ldots \quad \ldots \quad (63)$$

we have

$$R_e = \frac{1}{\omega C_0}\left(\frac{B \sinh 2A - A \sin 2B}{\cosh 2A - \cos 2B}\right) \quad (64)$$

$$X_e = -\frac{1}{\omega C_0}\left(\frac{A \sinh 2A + B \sin 2B}{\cosh 2A - \cos 2B}\right) \quad (65)$$

For all except very inefficient aerials it will be permissible to put

$$\sinh 2A = 2A \quad \ldots \quad \ldots \quad (66)$$

$$\cosh 2A = 1 \quad \ldots \quad \ldots \quad (67)$$

so that the above expressions become

$$R_e = \frac{A}{\omega C_0}\left(\frac{2B - \sin 2B}{1 - \cos 2B}\right) \quad \ldots \quad (68)$$

$$X_e = -\frac{1}{\omega C_0}\left(\frac{2A^2 + B \sin 2B}{1 - \cos 2B}\right) \quad \ldots \quad (69)$$

The above expressions are in quite a simple form for calculation, but can be simplified still further if, as is usually the case, the aerial is being used at a wavelength which is long compared with its fundamental. The following table will be a guide in this matter.

$\lambda/\lambda_0 > 3.5$ series up to 5th power correct to .1 per cent.

series up to 3rd power correct to .5 per cent.

$\lambda/\lambda_0 > 2.4$ series up to 5th power correct to about 3 per cent.

In the above the series referred to is the series form for the sin and cosine of the angle $2B$, and λ_0 is the natural wavelength of the aerial.

Using the series form for *sin* and *cos* $2B$ up to the fifth power of the angle the expression for R_e reduces to

$$R_e = \frac{2AB}{3\omega C_0}(1 + 2B^2/15) \quad \ldots \quad (70)$$

and since

$$2AB = \omega C_0 R_0 \quad \ldots \quad (71)$$

and

$$B^2 = \omega^2 L_0 C_0 \text{ very approx.} \quad \ldots \quad (72)$$

$$R_e = \frac{R_0}{3}(1 + \tfrac{2}{15}\omega^2 L_0 C_0) \quad \ldots \quad (73)$$

In the same way the expression for the reactance reduces to

$$X_e = -\frac{1}{\omega C_0}\left(1 - \frac{\omega^2 L_0 C_0}{3} - \frac{\omega^4 L_0^2 C_0^2}{45}\right) \quad (74)$$

to the same degree of approximation.

Thus, for wavelengths two or three times the natural wavelength of the aerial, the latter behaves very nearly as shown in Fig. 3, *i.e.*, as a resistance in series with a capacity since the bracket terms are very nearly unity. *A standard aerial can therefore be represented very closely in this way over the broadcasting range of wavelengths.*

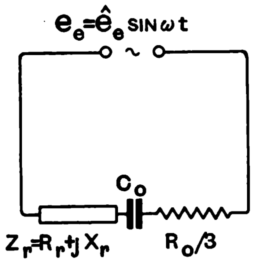


Fig. 3.

Taking as an example the typical case quoted above, and assuming a wavelength of 365 metres, then

$$R_e = \frac{50}{3}(1.037)$$

$$= 17.28 \text{ ohms.}$$

$$X_e = -1{,}135\ (1 - .092 - .0014)$$

$$= -1{,}135 \times .907$$

$$= -1030 \text{ ohms.}$$

Actually an aerial of this description would probably appear to have a resistance of 30 or 40 ohms, but the use of an earth screen would reduce this figure to about 15 ohms or so, showing that a considerable part of the apparent resistance is attributable to eddy current and other losses at the earth connection.

Resonance. Natural Wavelength.

Expressing the effective impedance in the form

$$Z_e = \mathbf{Z}_e \,\epsilon^{j\theta} \quad \ldots \quad \ldots \quad (75)$$

the resonant frequency can be defined by

$$d\mathbf{Z}_e/d\omega = 0 \quad \ldots \quad \ldots \quad (76)$$

or more conveniently in practice by

$$d\mathbf{Z}_e^2/d\omega = 0 \quad \ldots \quad \ldots \quad (77)$$

However, the differentiation with respect to ω will be laborious and cumbersome, and a better way of arriving at the resonance relation between ω and h will be to consider the frequency as a constant and find the corresponding critical value of h.

From equations (68) and (70),

$$z_e^2 = \frac{A^2 + B^2}{\omega^2 C_0^2} \frac{\cosh 2A + \cos 2B}{\cosh 2A - \cos 2B} \quad (78)$$

(This transformation is not given in detail as it is a standard one.) Equating to zero the differential coefficient with respect to h gives

$$(A' \sin 2A - B' \sin 2B)(\cosh 2A - \cos 2B) \quad (79)$$
$$-(A' \sinh 2A + B' \sin 2B)(\cosh 2A + \cos 2B) = 0$$

where A' has been written for dA/dh, etc.

and since A is proportional to h,

$$A' = A/h \quad \ldots \quad \ldots \quad (80)$$

Equation (79) reduces to

$$A \tanh 2A + B \tan 2B = 0 \quad \ldots \quad (81)$$

which is therefore the equation defining the resonance relation between ω and h.

If A is negligibly small this becomes

$$B \tan 2B = 0 \quad \ldots \quad (82)$$

which gives the well-known result for the fundamental

$$\omega_0^2 L_0 C_0 = \pi^2/4 \quad \ldots \quad (83)$$

For given values of A and B the solution of the resonance equation could be found by means of tables, but since A will always be small, the following process will give a close idea of the effect of the resistance on the natural wavelength of the aerial. If we put

$$2B = (\pi + \alpha) \quad \ldots \quad (84)$$

where α is some unknown small angle, it is easy to derive from 81, substituting $2A$ for $A \tanh 2A$, the equation

$$\alpha^2 + \alpha\pi + A^2 = 0 \quad \ldots \quad (85)$$

so that

$$\alpha = -A^2/\pi \text{ (approx.)} \quad \ldots \quad (86)$$

and since

$$B^2 = A^2 + \omega_0^2 L_0 C_0 \text{ (see eq. (61), } \omega = \omega_0) \quad (87)$$

therefore

$$\omega_0 = \frac{\pi}{2\sqrt{L_0 C_0}}\left(1 - \frac{3A^2}{\pi^2}\right) \quad \ldots \quad (88)$$

$$= \frac{\pi}{2\sqrt{L_0 C_0}}\left(1 - \tfrac{3}{4}\,\frac{C_0 R_0^2}{L_0}\right) \text{ (approx.)} \quad (89)$$

Now $L_0 C_0 = h^2/u^2$ (very approximately) (90)
(see formulæ for L and C)

where

$$u = 3 \times 10^{10} \text{ cms/sec.} \quad \ldots \quad (91)$$

and

$$\omega_0 = 2\pi u/\lambda_0 \quad \ldots \quad (92)$$

where λ_0 is the natural wavelength of the aerial.

Substituting these values in the equation for ω_0 gives

$$\lambda_0 = 4h\left(1 + \frac{3\,h^2 R_0^2}{4 \times 9 L_0^2} 10^{-20}\right) \quad \ldots \quad (93)$$

$$= 4h\left(1 + \frac{h^2 R_0^2}{12 L_0^2} 10^{-20}\right) \quad \ldots \quad (94)$$

Thus the effect of the resistance of the aerial is seen to be a very small increase in the natural wavelength of the aerial. In general, however, the effect will be negligibly small. For instance, taking the figures of the typical case quoted above, we have

$$\lambda_0 = 4h(1.005)$$

a difference of only five parts in a thousand.

For all practical purposes, therefore, we may take the natural wavelength as four times the total length (*i.e.*, $h_1 + h_2$) of the aerial. Therefore

$$B^2 = \omega^2 L_0 C_0 \quad \ldots \quad (95)$$

$$= \frac{\pi^2 \lambda_0^2}{4\lambda^2} \quad \ldots \quad \ldots \quad (96)$$

$$= \frac{4h^2\pi^2}{\lambda^2} \quad \ldots \quad \ldots \quad (97)$$

and equations (73) and (74) for the effective resistance and reactance can be put in the forms

$$R_e = \frac{R_0}{3}\left(1 + \frac{8\pi^2 h^2}{15\lambda^2}\right) \quad \ldots \quad (98)$$

$$X_e = -\frac{1}{\omega C_0}\left(1 - \frac{4\pi^2 h^2}{3\lambda^2} - \frac{16\pi^2 h^2}{45\lambda^2}\right) \quad (99)$$

Effective Height.

Of the questions put in the introduction the first three are now answered completely. The remaining two will now be considered.

For simplicity we will consider first the somewhat academic case of a plain aerial, vertical, and parallel to a uniform field. (See equations (44) and (45).) The effective E.M.F. has been shown to be

$$\mathbf{e}_e = \frac{h}{Ph} \tanh \frac{Ph}{2} \mathbf{e} \quad \ldots \quad (100)$$

where $\mathbf{e}=\hat{E}\ sin\ \omega t$ is the uniform field intensity. Putting this in the form

$$\mathbf{e}_\epsilon = H\epsilon^{j\varphi}\mathbf{e} \quad \ldots \quad \ldots \quad (101)$$

then H is the effective height of the aerial, since HE is the amplitude of the total E.M.F. acting in series with the effective aerial impedance and the tuning impedance. From equation (100)

$$H^2 = \frac{h^2}{A^2+B^2}\frac{\cosh A - \cos B}{\cosh A + \cos B} \ldots \quad (102)$$

(This transformation is not given in detail as it can easily be verified.)

In nearly all practical cases, it will be permissible to put $\cosh A=1$ to an accuracy better than 1 per cent, so that

$$H^2 = \frac{h^2}{A^2+B^2}\frac{1 - \cos B}{1 + \cos B} \quad \ldots \quad (103)$$

$$= \frac{h^2}{A^2+B^2}\tan^2 B/2 \quad \ldots \quad (104)$$

therefore

$$H = \frac{h}{\sqrt{A^2+B^2}}\tan B/2$$

This is in a form quite convenient for calculation without further approximation. For instance, assuming that the typical aerial already considered is wholly vertical,

$$H = \frac{\tan\ (.5244\ \text{radians}/2)}{\sqrt{.042^2 + .5244^2}}\ h.$$

$$= .512\ h$$

To show better the character of the expression in the case where A^2 is negligible compared with B^2, and where λ is two or three times the natural wavelength of the aerial, the tangent can be expressed in series form up to, say, the fifth power, giving

$$H = \frac{h}{B}\left(\frac{B}{2}+\frac{B^3}{24}+\frac{B^5}{240}\right) \quad \ldots \quad \ldots \quad (105)$$

$$= \frac{h}{2}\left(1 + \frac{B^2}{12}+\frac{B^4}{120}\right) \quad \ldots \quad \ldots \quad (106)$$

$$= \frac{h}{2}\left(1 + \frac{\pi^2}{48}\frac{\lambda_0^2}{\lambda^2}+\frac{\pi^4}{1920}\frac{\lambda_0^2}{\lambda^2}\right) \quad (107)$$

$$= \frac{h}{2}\left(1 + \frac{\pi^2}{3}\frac{h^2}{\lambda^2}+\frac{2}{15}\frac{\pi^4 h^4}{\lambda^4}\right)^* \quad (108)$$

Thus in general H is very nearly equal to $h/2$.

* In Mr. Moullin's paper this is given to the first two terms as $\frac{h}{2}\left(1 + \frac{\pi^2 h^2}{4\lambda^2}\right)$ but this is an obvious slip.

A much more important case in practice is that corresponding to the typical aerial considered as a numerical example, *i.e.*, the case in which the aerial is partly vertical and partly horizontal, the vertical part being parallel to a uniform field. (See equation (52).) The effective E.M.F. is given by

$$\mathbf{e}_\epsilon = \frac{\cosh\,(A+jB) - \cosh(A_2+jB_2)}{\sinh\,(A+jB)}\frac{h}{Ph}\,\mathbf{e} \quad (109)$$

where

$$Ph_2 = A_2+jB_2 \quad \ldots \quad (110)$$

The derivation from this expression of the value of H is somewhat lengthy, but follows exactly the same lines as in the simpler case, and need not be given in detail. The result is

$$H^2 = (2h^2/A^2+B^2)\frac{\{\cosh(A+A_2)-\cos\overline{B+B_2}\}\{\cosh(A-A_2)-\cos(B-B_2)\}}{(\cosh 2A - \cos 2B)} \quad (111)$$

If A is small and A^2 negligible compared with B^2, this reduces to

$$H^2 = \frac{2h^2}{B^2}\frac{(1-\cos\overline{B+B_2})\,(1-\cos\overline{B-B_2})}{(1-\cos 2B)} \quad (112)$$

whence

$$H = \frac{h}{B}\frac{\cos B - \cos B_2}{\sin B} \quad \ldots \quad (113)$$

For the numerical case already considered

$$B = 2.544\ \text{radians} = 30°\ 3'$$
$$B_2 = .7 \times .2544\ \text{radians}$$
$$= .367\ \text{radians}$$
$$= 21°$$

and the substitution of these values in the formula gives

$$H = .266\ h$$

and since $h_1 = .3\ h$

it will be seen that the effect of the horizontal part is to make the effective height very nearly equal to the actual vertical height. This shows the advantage of having a fairly long horizontal part to the aerial in cases where the vertica height is limited. It also shows that in the above typical case very little is to be gained by doubling or trebling the top wires, certainly not much more than about 10 per cent. This conclusion is quite in agreement with measurements made on small receiving aerials by the writer in conjunction with Dr. Smith-Rose, described in the article referred to above.

Moreover, the form of the expression for the vertical height shows clearly that the best distribution of a given total length of aerial is to have the whole length vertical. That is to say, there is no best distribution as between vertical and horizontal parts for a given total length. This is illustrated by the curve of Fig. 4, which shows effective height plotted against h_2 for the numerical case considered. This provides the answer to Question 5.

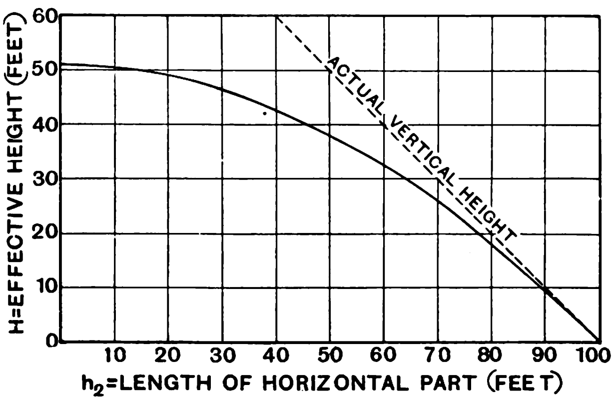


Fig. 4.

SUMMARY.

It will be well to conclude the paper with a re-statement of the initial questions giving to each the answer that has been found in the course of the analysis. The answers will be given in as widely applicable a form as possible, but for convenience some of the more important specific formulæ will be quoted. Unless otherwise stated these refer to an aerial of height h_1 (vertical) with a horizontal top of length h_2 situated in a uniform vertical field. The vertical and horizontal parts of the aerial are considered to have the same uniform electrical constants L, C, and R per unit length, the total resistance inductance and capacity, *i.e.*, $R(h_1+h_2)=Rh$, etc., being represented by R_0, L_0, and C_0. The natural wavelength of the aerial will be called λ_0.

1. *What is the nature of the effective impedance of a receiving aerial from the point of view of associated receiving apparatus?*

From the point of view of an inserted receiving or tuning circuit the aerial can be regarded as an ordinary impedance of the type (R_e+jX_e) in series with a certain effective E.M.F. due to the signal. The resistance component of the aerial impedance will not vary greatly with frequency if the wavelength of the signal is two or three times the natural wavelength of the aerial. Under the same conditions the effective reactance can be represented very closely as that of the total aerial capacity. For the case described above the following formulæ are applicable if the wavelength is two or three times that of the aerial.

$$R_e = \frac{R_0}{3}\left(1 + \frac{8}{15}\,\frac{\pi^2 h^2}{\lambda^2}\right)$$

$$X_e = -\frac{1}{\omega C_0}\left(1 - \frac{4}{3}\,\frac{\pi^2 h^2}{\lambda^2} - \frac{16}{45}\,\frac{\pi^4 h^4}{\lambda^4}\right)$$

The accurate formulæ for the general case are given in equations (64) and (65).

2. *Is the effective impedance dependent on (a) the nature of the tuning or receiving circuit; (b) the distribution of the electric field to the signal?*

The effective impedance depends *only* on the electrical constants and the configuration of the aerial.

3. *What part is played by the distributed resistance of the aerial?*

The distributed resistance of the aerial enters into the resistance component of the effective impedance and also, though not considerably, into the effective reactance. It is one of the factors which limits the current at the base of the aerial when the latter is tuned to resonance with the signal E.M.F. It is, however, only one of the factors which limits the resonance current, the others (eddy current and other losses in the earth connection and the resistance of the tuning impedance) being in general of at least equal and probably greater effect. (For formulæ see Question 1.)

4. *What is the effective height of an aerial; and does it depend on (a) the tuning circuit conditions, (b) the field distribution?*

The aerial circuit can be shown to be equivalent to a certain effective E.M.F. in series with the effective aerial impedance and the tuning circuit impedance. The term, effective height, can only be applied if the field can be considered uniform. The effective height can then be defined as the magnitude of the total E.M.F. divided by the magnitude of the field intensity. Thus, if the effective E.M.F. is given by

$$\mathbf{e}_e = H\epsilon^{j\varphi}\mathbf{e}$$

where e is the field intensity, then H is the effective height for reception.

For a plain vertical aerial in a uniform vertical field—

$$H^2 = \frac{h}{A^2 + B^2} \frac{\cosh A - \cos B}{\cosh A + \cos B}$$

where

$$A = \frac{R}{2} \sqrt{\frac{C_0}{L_0}}$$

$$B = \omega \sqrt{L_0 C_0} \left(1 + \frac{R_0^2}{8\omega^2 L_0^2}\right)$$

assuming that $R_0^4/\omega^4 L_0^4$ is negligibly small compared with (1). In practice H will be very nearly to $h/2$. Other formulæ are given in equations (111) and (113).

The effective height is not effected by the tuning of the aerial, but depends on the frequency and on the field distribution. It is thus not a specific constant for any given aerial structure, but can be made so for purposes of definition by assuming a uniform vertical field.

5. *Is there any optimum distribution for a given length of aerial?*

No perfectly general answer can be given to this question since the effective height and therefore the effectiveness of the aerial depend on the configuration of the field in which it is situated. In the case of a uniform vertical field, however, the best possible arrangement for a given total length is wholly vertical.

In conclusion, the writer would like to point out that though the above conclusions are entirely consistent with his own experience with small receiving aerials, there is clearly need for experimental confirmation or otherwise of much of the detail, and also of the extent to which the assumptions with regard to the effective uniformity of the aerial constants are really valid in practice. It is partly in the hope of stimulating such experimental work that the above paper has been published.

NOTE BY THE AUTHOR.

This article was written nearly two years ago but I have not had occasion to modify any of the conclusions reached in the light of further consideration or experience. Moreover, a certain amount of experimental work on this subject has recently been carried out at the National Physical Laboratory, by Mr. Wilmotte, and the results obtained are substantially in agreement with the main deductions of the theoretical investigation given above. It is hoped that some account of Mr. Wilmotte's work on the subject will shortly be available for publication.—F. M. COLEBROOK.

X-Rays and Radio Valves.

By J. Taylor, D.Sc. (Utrecht), M.Sc., Ph.D., A.Inst.P.

WHEN anybody mentions X-rays we usually think at once of the radiation coming from great bulbs driven by some fifty or more kilovolts, high power installations such as are used for radiographic and medical purposes.

Such radiations are what is technically termed "hard," and are not readily absorbed in substances. Their wavelength is of the order of 10^{-8} cms.—that is, one hundredth of a millionth of a cm. Ordinary visible light on the other hand has a wavelength of the order of 5×10^{-5} cms.—fifty millionths of a cm. We thus see immediately what a large difference of magnitude exists between the two types of waves.

In a general way it is found that the greater the voltage driving an X-ray bulb the "harder" the radiation emitted from it, or in other words, the smaller the wavelength of the radiation. Indeed the frequency of the hardest radiation from a tube is given by the quantum relation $\eta = V/c$, where V is the voltage across the bulb and c is a constant. Alternatively we may express this relation in terms of wavelengths and obtain the relation, $V \times \lambda = 12{,}340$, where λ is the wavelength of the hardest radiation, expressed in ångstrom units (the usual unit for ordinary radiation wavelengths).

It is possible by utilising X-ray bulbs of the Coolidge type in which the cathode consists of a glowing filament of tungsten placed very near to an anticathode or target—suitably of tungsten—mounted in a highly exhausted vessel, to obtain X-radiation with very much smaller voltages across the tube. In this way X-rays corresponding to three or four hundred volts may be examined—that is of the order of 50×10^{-8} cms. (50 ångstroms). Such radiations are characterised by great absorbability, thin films of celluloid of as little as ten millionths of a cm. in thickness, absorbing 90 per cent. of the radiation. The rays are consequently completely absorbed in the walls of the bulb and their

properties cannot be examined outside in the surrounding space. Several methods, however, can be utilised to measure some of their properties, within the tube itself.

When the radiation passes through gases strong ionisation is produced, the gas molecules and atoms being split up into

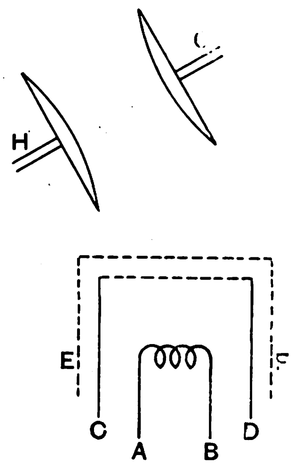


Fig. 1. *Type of tube shown diagrammatically.*

positive and negative parts—that is positive ions, and negative ions and electrons—the gases become to a certain extent electrically conducting and if suitable means are taken, a current passing through the gas may be measured. Also, if the radiations fall against a negatively charged plate, electrons (particles of negative electricity) are given off or expelled from the surface of the metal due to the photo-electric action of the radiation upon it. Either of the above described actions may be utilised for the detection and measurement of the soft X-rays.

When such low voltage X-ray bulbs are used it is necessary to maintain a very high vacuum within them, and to freeze out by means of a liquid air trap all traces of mercury vapour (mercury is almost universally used in high vacuum pumps and so is always present in the apparatus unless special precautions are taken to freeze it out).

If traces of gas or mercury vapour—even at a pressure of less than a millionth of an atmosphere—remain in the tube, the type of radiation emitted becomes immediately softer—that is of greater wavelength—because it is then to a large extent produced by the impact of the electrons against the gas or vapour molecules in the tube, or absorbed as a thin film upon the anticathode surface, and the radiation accompanying such collisions corresponds to teens of volts instead of to a few hundred volts. At the same time, however, the output of radiations or total intensity is very much increased.

We may state then that it is a general property that when electrons strike against a metal target radiation is emitted, or when they impinge against gas molecules and have sufficient energy, they produce not only ionisation of the gas but give rise to radiations from the gas atoms and molecules.

In principle then every diode or triode valve is a generator of X-radiation of long wavelength. The quantity generated may, of course, be very small but it nevertheless must exist.

The writer has recently carried out experiments which show this property. Fig. 1 shows diagrammatically the type of tube employed. *AB* is a tungsten filament, *CD* a nickel cylinder provided with a nickel gauze window at its upper end and surrounding the filament, *EF* is a gauze grid which completely encloses the cylinder

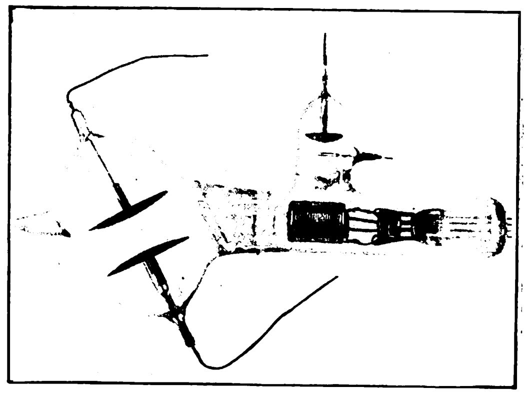


Fig. 2. *Photograph of the tube showing position of the electrodes.*

system. *CD* is utilised as plate and the electron current flows between *AB* and *CD*. *EF* is charged to such a potential as to prevent any escape of electrons or ions from the cylinder-filament system. The two metal (nickel) electrodes *G* and *H* are

situated as shown in the photograph, Fig. 2, and *EF*, so that *G* is in view of the opening or window in the cylinder *CD*. The apparatus was exhausted to as high a vacuum as possible and thoroughly "baked out" and "glowed out" for many hours. A liquid air trap was also used.

The X-radiation was detected and measured by means of the photo-electric effect produced at the electrode *G*. The photo-electric currents were measured by means of a sensitive galvanometer. It was found that no current flowed between *G* and the filament *AB* provided that *G* was at a fairly high positive potential with respect to the filament. This shows definitely, therefore, that no electrons were gathered from the filament by the electrode *G*. When *G* became of the order of some volts positive however a small current was indicated and this current increased as the potential of *G* was increased in the negative direction, until finally a saturation value was reached.

Similar results were obtained by measuring the current between the electrodes *G* and *H*. The maximum currents obtained were of the order of about 5×10^{-10} amps.

There is no reasonable doubt but what the currents were produced by the photo-electric action of radiation proceeding from the bombardment of the cylinder by the filament electrons, for further investigation showed that the current exhibited the properties of photo-electric emissions and was definitely not due to the photo-electric action of the light emitted by the filament.

When the liquid air was removed so that mercury vapour—the vapour of mercury at room temperature has a pressure of less than a millionth of an atmosphere—entered the tube an increase of some ten or fifteen fold in the photo-electric current occurred due to the soft radiation produced by the bombardment of the electrons against the mercury atoms and to a certain extent the creation of a positive space charge.

These experiments show definitely, as indeed previous experiments along similar lines have done, that there must be production of soft X-radiation within the diode and triode valves used in practice. This soft X-radiation is intensely ionising and can produce considerable photo-electric effects on metallic and other substances. In hard valves such radiation must exist though most probably in small amount. In soft valves, however, there is a possibility of considerable production of radiation which will in turn bring about photo-electric emissions from the cathode—filament—and ionisation within the gas. When traces of substances such as the alkali metals which exhibit very great photo-electric emissivity are included in the tubes such photo-electric effects may conceivably become important.

The Performance of Valves in Parallel.

By R. P. G. Denman, M.A., A.M.I.E.E.

THERMIONIC valves are commonly used in parallel as a convenient method of obtaining large power output without the necessity for designing special valves for every requirement. It is evident from the performance of large banks of valves that good efficiencies can be obtained, but in view of the fact that no two valves are ever likely to have precisely similar characteristics, it may be of interest to examine the general case of a number of valves operating in parallel on a common load. We shall then be in a position to judge the extent of the losses which are liable to occur in practice, and decide how far it may be necessary, or possible, to redress the balance by means of separate grid bias, etc., for individual valves.

1. Theoretical Case of n Batteries in Parallel.

We will begin by establishing one or two formulæ concerning the general type of network shown in Fig. 1. Applying Kirchhoff's First and Second Laws we have :—

$$I = i_1 + i_2 + i_3 + \dots + i_n$$
$$V_1 = i_1 r_1 + IR_e$$
$$V_2 = i_2 r_2 + IR_e$$
$$\dots\dots$$
$$V_n = i_n r_n + IR_e$$
$$\therefore \quad i_1 = \frac{V_1}{r_1} - \frac{IR_e}{r_1} \quad \dots \quad \dots \quad (1)$$

and similar equations, which added together give :—

$$I = \left(\frac{V_1}{r_1} + \frac{V_2}{r_2} + \dots + \frac{V_n}{r_n}\right) - IR_e\left(\frac{1}{r_1} + \frac{1}{r_2} + \dots \frac{1}{r_n}\right) \quad (2)$$

Designating this as

$$I = \Sigma^n \frac{V}{r} - IR_e \Sigma^n \frac{1}{r} \quad \dots \quad (3)$$

we obtain

$$I = \frac{\Sigma^n \frac{V}{r}}{1 + R_e \Sigma^n \frac{1}{r}} \quad \dots \quad \dots \quad (4)$$

Substituting this value for I in equation (1) we get :—

$$i_1 = \frac{V_1 - IR_e}{r_1} = \frac{V_1}{r_1} - \frac{R_e \Sigma^n (V/r)}{r_1(1 + R_e \Sigma^n (1/r))}$$

$$i_2 = \frac{V_2 - IR_e}{r_2} = \frac{V_2}{r_2} - \frac{R_e \Sigma^n (V/r)}{r_2(1 + R_e \Sigma^n (1/r))}$$

In the special case $n=2$ we find that

$$I = \frac{V_1 r_2 + V_2 r_1}{r_1 R_e + r_2 R_e + r_1 r_2} \quad \dots \quad (5)$$

$$i_1 = \frac{V_1 R_e + V_1 r_2 - V_2 R_e}{r_1 R_e + r_2 R_e + r_1 r_2} \quad \dots \quad (6)$$

$$i_2 = \frac{V_2 R_e + V_2 r_1 - V_1 R_e}{r_1 R_e + r_2 R_e + r_1 r_2} \quad \dots \quad (7)$$

It is to be noted that i_2 becomes zero when

$$R_e = \frac{V_2}{V_1 - V_2} r_1$$

and negative when R_e exceeds this value. The condition that any current is positive is that

$$V_n > IR_e$$

Thus if R_e increases until the current in one of the branches becomes zero, the first to suffer will be that having the smallest E.M.F.

Now let the load R_e be short-circuited. Then the total current I (equation (4)) is

$$I = \Sigma^n (V/r)$$

The total internal resistance is the sum of $r_1, r_2, r_3 \dots r_n$ in parallel (called hereafter $\Sigma^n r_{(\text{parallel})}$) and it follows that any number of batteries are equivalent in effect to a single unit having an E.M.F.

$$\Sigma^n (V/r) \times \Sigma^n r_{\text{(parallel)}}$$

and an internal resistance $\Sigma^n r_{\text{(parallel)}}$. The power on short-circuit is therefore

$$(\Sigma^n (V/r))^2 \times \Sigma^n r_{\text{(parallel)}} \quad \dots \quad (8)$$

It will be convenient before passing on to the case of valves in parallel to obtain an expression for the equivalent resistance external to any element of the network of

Fig. 1. The total resistance external to any E.M.F. V_n is

$$\frac{V_n}{i_n}-r_n.$$

If $n=2$ we have (from equation (6))—

Resistance external to V_1

$$=\frac{V_1}{i_1}-r_1$$

$$=\frac{V_1(r_1R_e+r_2R_e+r_1r_2)}{V_1R_e+V_1r_2-V_2R_e}-r_1$$

$$=R_e\frac{(V_1r_2+V_2r_1)}{V_1r_2+V_1R_e-V_2R_e} \quad \cdots \quad (9)$$

If $V_1=V_2$ and $r_1=r_2$ this becomes $2R_e$ which is seen to be correct as the external current is shared equally between the batteries.

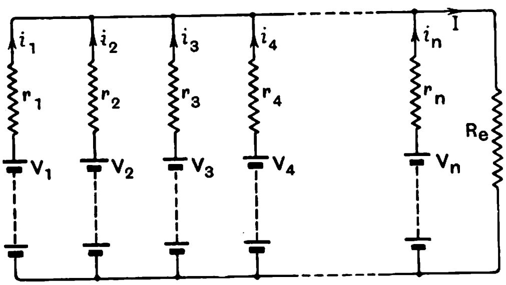


Fig. 1.

Again, if

$$R_e=\frac{V_2}{V_1-V_2}\cdot r_1$$

so that $i_2=0$, equation (9) reduces to R_e.

The apparent external resistance, looking into the circuit from V_2, can similarly be shown to be—

Resistance external to V_2

$$=R_e\frac{V_1r_2+V_2r_1}{V_2r_1-V_1R_e+V_2R_e} \quad \cdots \quad (10)$$

Equations (9) and (10) warn us to beware of assuming that all the valves in one bank are necessarily working into the same effective load.

2. Application to Case of n Valves in Parallel.

We are now in a position to consider the network of Fig. 2, where the batteries are replaced by valves having unilateral conductivity. Since we are only concerned with A.C. values we may regard the valves as alternators developing E.M.F.s of maximum value $\mu_1\,\mu_2,\ldots\mu_n$ times the common applied grid voltage δv_g. If we assume in the first instance that the region of linear operation is unlimited in the positive direction, and continues without modification down to zero anode current, we may

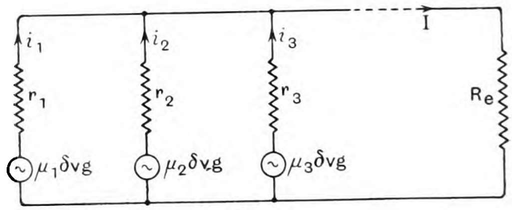


Fig. 2.

note first that although the total current always increases with the applied grid voltage (equations (5), (6), (7)), there may be one or more valves in which the anode current falls as the total current rises, this effect depending upon the magnitude of the external resistance R_e. This condition is illustrated by actual curves in Fig. 3, which shows the resulting anode current in the extreme case of an LS5 and an LS5B valve operating in parallel with a common external resistance of 20,000 ohms. Curves A and B refer to the LS5 and LS5B valves separately and represent the anode current

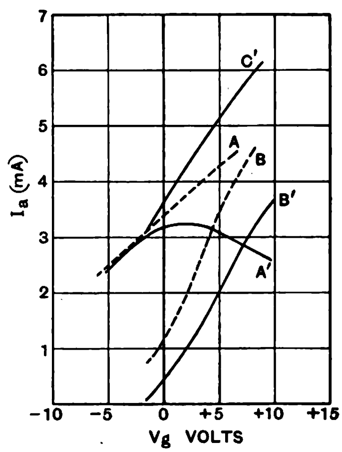


Fig. 3.

at 120 volts with the above value of external resistance. Curves A' and B' represent the separated anode currents for the same two valves when operating in parallel, while Curve C' gives the resulting anode current

through the resistance. It is seen that over a certain portion of the characteristics, where μ and r have appropriate values, the anode current change for the LS5 is zero or negative, although the total change of anode current is always positive.

The following example will serve to show that this result is not necessarily restricted to those cases in which the valve characteristics are intentionally dissimilar. From half-a-dozen valves of the same (LS5A) type, two were chosen as having the following values of amplification factor and anode A.C. resistance :—

		Amplification factor.	Anode A.C. resistance.
No. 1	...	$\mu_1=2$	$r_1=3{,}000$ ohms.
No. 2	...	$\mu_2=2.19$	$r_2=3{,}350$ ohms.

Now it is shown graphically in an important article by E. Green* on "The Use of Plate-Current Plate-Voltage Characteristics" that the external resistive load can profitably be made 11.5 times the anode A.C. resistance of the type of valve we are considering, *i.e.*, with two perfectly matched valves of 3,000 ohms each in parallel, R_e may be $11.5\times1{,}500=17{,}200$ ohms if V_a is in the neighbourhood of 500 volts. It would appear, however, from the above result that the use of so high an external resistance in association with valves placed in parallel (without extremely careful selection) would lead to serious losses.

If the reader cares to compare the theoretical short-circuited outputs for a few selected cases by means of equation (8), he

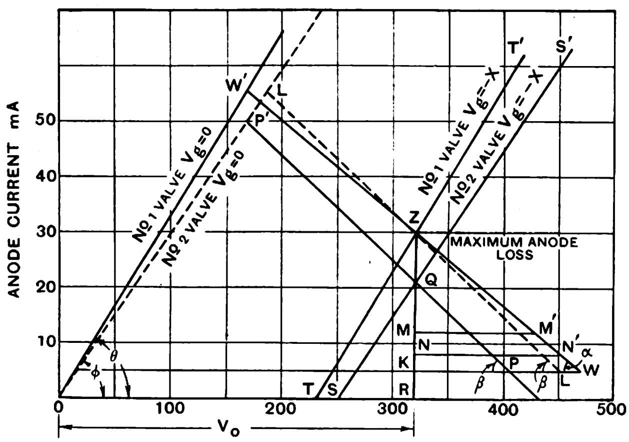


Fig. 4.

The difference between μ_1 and μ_2 is 10 per cent. while μ_1/r_1 and μ_2/r_2 are nearly equal. If these two valves are paralleled and connected to a common resistive load R_e, equation (6) shows that if

$$R_e=\frac{\mu_1}{\mu_2-\mu_1}\times r_2=35{,}000 \text{ ohms approx.}$$

i_1 will become vanishingly small (zero with linear characteristics), while if R_e exceeds this value, i_1 will be "negative" (*i.e.*, 180 degrees out of phase with i_2).

It can also be shown by means of equations (5) and (6) that No. 1 valve will only be contributing one-third of the total current I when

$$\frac{i_1}{I}=\frac{1}{3}=\frac{\mu_1R_e+\mu_1r_2-\mu_2R_e}{\mu_1r_2+\mu_2r_1}$$

i.e., when $R_e=12{,}000$ ohms approx.

will find that even here there is a loss of power resulting from a combination consisting of $n/2$ valves having μ and r values (say) 10 per cent. above, and $n/2$ valves—having values 10 per cent. below some nominal value. Were the characteristics linear this loss would not be of much importance, amounting to about 5 per cent. in a typical case.† But as the constants of the valves are made to differ more widely, the currents i_1 and i_2 (equations (6) and (7)) diverge more and more above and below equality. That is to say, that of two valves in which $\mu_1>\mu_2$ and $r_1>r_2$, the valve with

* *E.W. & W.E.*, July-August, 1926. The ensuing discussion is based on the methods therein described.

† The percentage loss is independent of n.

the higher amplification factor μ_1 is called upon to deliver a larger current than the other valve, which is therefore working inefficiently. Moreover, if the grids are held at a common negative potential, this potential must be chosen so that the valve with lowest amplification factor is limited to some definite anode loss (about 10 watts in the present case).

Let us see how this affects the conditions of mutual operation. Returning to the numerical example with which we began this section, Fig. 4 shows a portion of the I_a—V_a characteristics for the two valves. No D.C. loss is assumed in the feed circuits and the valves are working into resistive loads $R_{e1} = \cot \alpha$ and $R_{e2} = \cot \beta$. These loads are obtained from equations (9) and (10) and represent for each valve an arbitrary external load of $R_e = 2{,}800$ ohms, as modified by the presence of the other valve. Thus :—

Load external to No. 1 valve

$$= \cot \alpha = R_{e1}$$

$$= R_e \frac{(\mu_1 r_2 + \mu_2 r_1)}{\mu_1 R_e + \mu_1 r_2 - \mu_2 R_e}$$

$$= 2{,}800 \frac{(2 \times 3{,}350 + 2.19 \times 3{,}000)}{(2 \times 2{,}800 + 2 \times 3{,}750 - 2.19 \times 2{,}800)}$$

$$= 2{,}800 \times 2.15$$

$$= 6{,}000 \text{ ohms.}$$

Load external to No. 2 valve

$$= \cot \beta = R_{e2}$$

$$= R_e \frac{(\mu_1 r_2 + \mu_2 r_1)}{\mu_2 r_1 - \mu_1 R_e + \mu_2 R_e}$$

$$= 2{,}800 \frac{13{,}270}{2.19 \times 300 - 2 \times 2{,}800 + 2.19 \times 2{,}800}$$

$$= 5{,}300 \text{ ohms.}$$

If TT' is the line of constant grid voltage $(-x)$ on the set of characteristics for No. 1 valve, and SS' represents the same voltage for No. 2 valve, we have

$$\frac{OT}{\mu_1} = \frac{OS}{\mu_2} \quad \ldots \quad \ldots \text{(11)}$$

Since both valves must be restricted to a certain anode dissipation, assumed in this case to be 0.03A at 320 volts, $ZR = 0.03$A is the steady current for No. 1 valve. Also, under the conditions enumerated, the steady current of No. 2 valve is seen to be $QR =$ 0.021A,* while the maximum distortionless power output† from this valve (taking 5mA as the minimum anode current) is :—

$$\tfrac{1}{2}.QK.KP = \tfrac{1}{2} \times 0.016 \times 85 = 0.68 \text{ watt.}$$

We can determine the excursion of anode current for No. 1 valve corresponding to the excursion QK for No. 2 by means of equations (6) and (7).

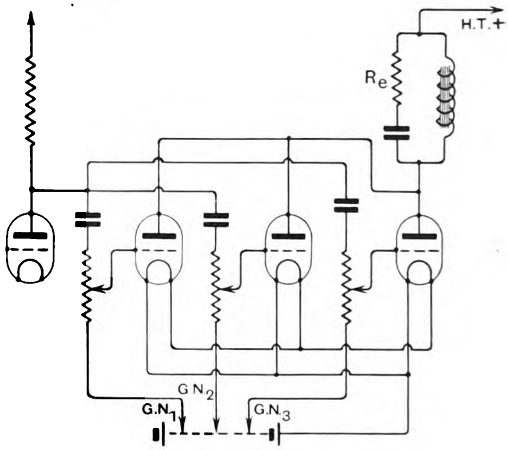


Fig. 5.

Thus

$$\frac{i_1}{i_2} = \frac{\mu_1 R_e + \mu_1 r_2 - \mu_2 R_e}{\mu_2 R_e - \mu_2 r_1 - \mu_1 R_e}$$

where $R_e = 2{,}800$ ohms.

---

* The value of the steady current i_2 in No. 2 valve relative to the current i_1 in No. 1 can be obtained for the general case as follows :—

We have, from equation (11)

$$OS = \frac{\mu_2}{\mu_1} OT$$

$\therefore$ $$TS = \psi OT, \text{ where } \psi = \frac{\mu_2}{\mu_1} - 1$$

$\therefore$ $$TS = \psi(OR - TR) = \psi(V_0 - i_1 \cot \theta)$$

also $$SR = TR - TS$$

$$= i_1 \cot \theta - \psi V_0 + \psi i_1 \cot \theta$$

$\therefore$ $$QR = i_2 = SR \tan \phi$$

$$= i_1 \cot \theta \tan \phi - \psi V_0 \tan \phi + \psi i_1 \cot \theta \tan \phi.$$

But $\cot \theta = r_1$ and $\tan \phi = 1/r_2$

$\therefore$ $$i_2 = i_1 \left(\frac{r_1}{r_2} + \psi \frac{r_1}{r_2}\right) - \psi \frac{V_0}{r_2}$$

$$= \frac{\mu_2 r_1}{\mu_1 r_2} i_1 - \frac{V_0}{r_2}\left(\frac{\mu_2}{\mu_1} - 1\right)$$

If $\mu_2 > \mu_1$ and $\mu_1/r_1 = \mu_2/r_2$, it is seen that i_2 is always less than i_1.

† By distortionless output it is meant that grid current and bottom-bend working are excluded.

$$\therefore \quad i_1 = i_2 \times \frac{2 \times 2{,}800 + 2 \times 3{,}350 - 2.19 \times 2{,}800}{2.19 \times 2{,}800 + 2.19 \times 3{,}000 - 2 \times 2{,}800}$$

$$= 0.016 \times \frac{6{,}168}{7{,}100} \quad \ldots \quad \ldots \quad \ldots (12)$$

$$= 0.018\text{A} = ZM \text{ (Fig. 4).}$$

So that the worst-placed valve (No. 2) controls the situation, and No. 1, although potentially capable of handling larger input, cannot receive this without No. 2 becoming overloaded. The total power output is 0.68 watt from No. 2 valve and

$\frac{1}{2}.ZM.MM' = \frac{1}{2} \times 0.018 \times 84.5 = 0.76$ watt from No. 1, or 1.44 watts in all.

It is evident that the use of separate grid bias adjustments will enable us to obtain a much better output. This is usually provided in transmitting circuits but would seem to be quite desirable also in receivers (power amplifiers) unless facilities exist for the selection of a suitable team of valves for parallel operation.

If, then, we arrange separate grid bias, No. 2 valve can be independently adjusted for about 10 watts anode dissipation, its working line then being LL' and its maximum output

$$\tfrac{1}{2}.ZK.KL = \tfrac{1}{2} \times 0.025 \times 130 = 1.62 \text{ watts.}$$

The anode current excursion for No. 1 valve is, by equation (12)

$$i_1 = i_2 \times \frac{6{,}618}{7{,}100}$$

$$= 0.022\text{A} = ZN$$

and the power output is

$$\tfrac{1}{2}.ZN.NN' = \tfrac{1}{2} \times 0.022 \times 130$$

$$= 1.43 \text{ watts.}$$

The total power output is now therefore $1.62 + 1.43 = 3.05$ watts, or more than twice the value obtained with common grid bias.

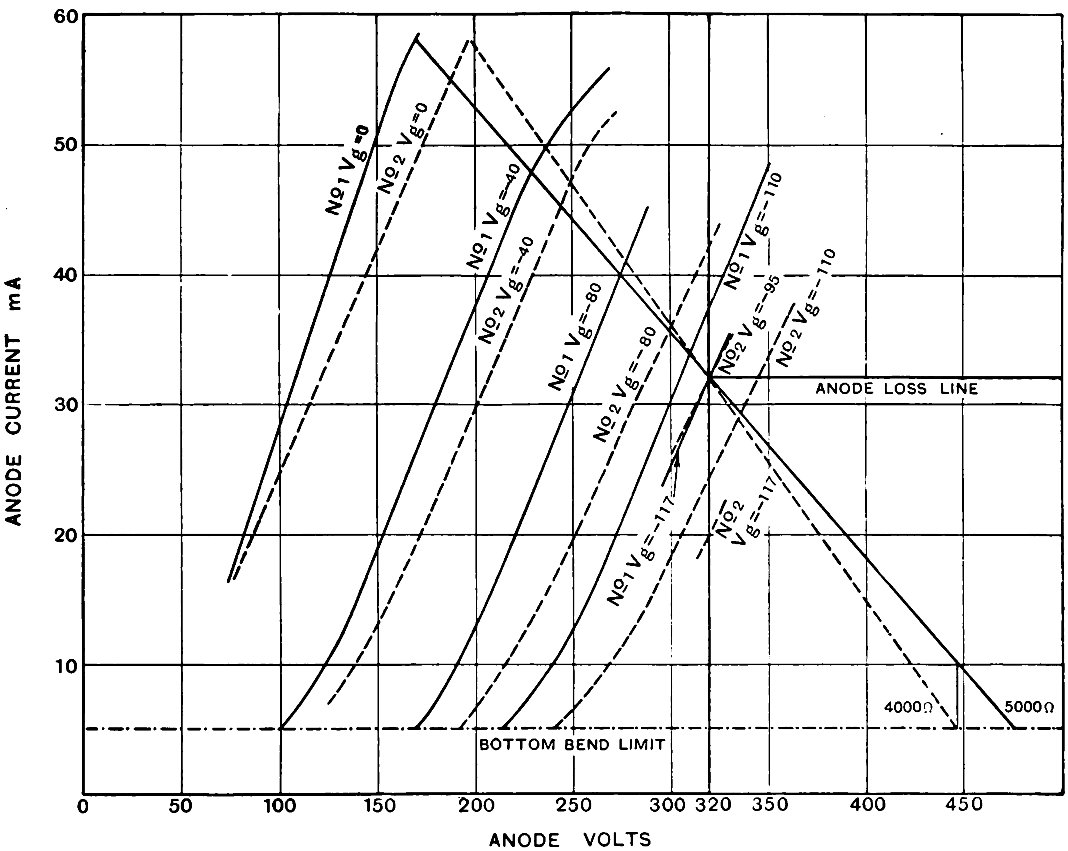


Fig. 6.

In order to carry the operating points of all the valves in any given bank to their extreme limits of distortionless working it would be necessary to apply to each grid a certain fraction of the alternating voltage developed by the previous valve. This could be adjusted by means of potentiometers in place of grid-leaks, as shown in Fig. 5. With transformer coupling a tapped secondary or a tapped resistance across the secondary would be used. In the case of the two valves given in the above example, the increase in output obtained by applying graded input voltages in addition to separate grid bias adjustments would be from $1.62 + 1.42 = 3.04$ watts to $1.62 + 1{,}875 = 3.5$ watts, or an increase of 15 per cent.

In conclusion, we may glance briefly at a further example in which the characteristics for two other LS5A valves have been observationally plotted (see Fig. 6). The constants in this case are as follows :—

	Amplification factor.	Anode A.C. resistance.
No. 1 ...	$\mu_1 = 1.76$	$r_1 = 2{,}800$ ohms.
No. 2 ...	$\mu_2 = 2$	$r_2 = 3{,}100$ ohms.

As before, we find that

$$\frac{\mu_1}{r_1} \div \frac{\mu_2}{r_2}\text{ ; also } \frac{\mu_2}{\mu_1} = 114 \text{ per cent.}$$

and

$$\frac{r_2}{r_1} = 110 \text{ per cent.}$$

In this case we shall at once apply separate grid bias, and we find that for No. 1 valve it must be —117 volts and for No. 2 —95 volts to limit the static dissipation in each valve to 10 watts, viz., 32mA at 320 volts. If the actual external load is 2,200 ohms, the apparent load on No. 1 valve comes out at 5,000 ohms and that on No. 2 at 4,000 ohms. Allowing a minimum anode current of 5mA it will be seen on reference to Fig. 6 that the maximum power from No. 2 valve is roughly

$$\tfrac{1}{2} \times \frac{25 \times 120}{1{,}000} \text{ watts} = 1.5 \text{ watts.}$$

The maximum power from No. 1 valve with common alternating grid voltage is

$$\tfrac{1}{2} \times \frac{21 \times 120}{1{,}000} = 1.25 \text{ watts,}$$

making a total of 2.76 watts. If, however, the input to No. 1 is separately applied, and increased to the maximum permissible value for this valve, the available power output is

$$\tfrac{1}{2} \times \frac{25 \times 150}{1{,}000} = 1.88 \text{ watts.}$$

giving a total of 3.38 watts. The improvement factor is therefore

$$\left(\frac{3.38}{2.76} - 1\right) \times 100 \text{ per cent.} = 22 \text{ per cent.}$$

Finally, with a bank of say five valves similar to No. 1 and one similar to No. 2, it is evident that the improvement factor would be considerably in excess of this figure.

It should be noted, however, that the percentage of second harmonics introduced by one *abnormal* valve is inversely proportional to the number of *normal* valves (with non-distorting adjustments) in parallel. Despite the numerical examples, therefore, it may be doubted whether the application to Modulators or Power Amplifiers of the method outlined above would give rise to very well-marked improvements. There remains also the fact that besides compensating valves for their varying "μ" values, their A.C. resistances ought also theoretically to be compensated by means of separate output transformers. Possibly manufacturers would solve the difficulty by undertaking to supply small groups of power valves having characteristics guaranteed to fall within close limits.

Resonance in Series and Parallel Circuits.

By H. J. Boyland, A.M.I.E.E.

IT would appear rather unfortunate that the term "resonance" was ever employed to describe certain electrical phenomena, inasmuch as its precise meaning when so used is by no means well defined, and the so-called conditions of resonance depend upon what interpretation is placed upon the term. It was first shown by Kelvin that the discharge of a condenser through a circuit containing inductance is of an oscillatory nature, provided that the resistance included in the circuit be below a certain limit. The frequency of this oscillatory discharge of the condenser is known as the "natural" or "free" oscillation frequency of the circuit, and, strictly speaking, resonance is the condition which exists when a sinusoidal E.M.F. of frequency equal to the natural frequency is applied to the circuit, and this is so whether the E.M.F. be applied to the condenser and inductance in series or in parallel. With the condenser and inductance in series the current which flows through the combination from the external source is limited only by the resistance of the circuit, and the potential differences across the inductance and across the condenser attain abnormal values, many times in excess of the applied E.M.F. The combination of an inductance and condenser in parallel, however, offers to an applied E.M.F. of frequency equal to the natural frequency an impedance of very high value, which results in the current flowing from the source being very small; moreover, in this case a large oscillating current surges round the closed circuit. If, however, the resistance be not negligible these effects do not have their maxima when the applied frequency is equal to the natural frequency and hence the above general definition of resonance ceases to be of any particular significance.

The object of this article is to analyse certain combinations of inductance, capacity and resistance in order to derive the relationship which must exist between these quantities to satisfy the various conditions set out below :—

For Series Circuits.

(*a*) Potential difference across inductance to be a maximum.

(*b*) Potential difference across capacity to be a maximum.

(*c*) Current through circuit to be a maximum.

For Parallel Circuits.

(*d*) Equivalent reactance of circuit to be zero.

(*e*) Impedance to be a maximum.

We shall consider the following circuits :—

Series Circuits.

1. Inductance and capacity in series without resistance.
2. Inductance, capacity, and resistance in series.
3. Inductance with included resistance in series with capacity.

Parallel Circuits.

4. Pure inductance (*i.e.*, without resistance) and pure capacity in parallel.
5. Inductance and resistance in parallel with pure capacity.
6. Inductance and resistance in parallel with capacity and resistance.

In every case we shall assume an applied sinusoidal E.M.F., *i.e.*, an alternating E.M.F. of pure sine wave form without harmonics, and that all inductances and capacities are concentrated. While it would be sufficient to deal with the most general case of each arrangement (series and parallel) it is felt that it will be more instructive to treat each case separately starting with the simplest. In general it will be found that the relationship between the constants of a circuit to satisfy any given condition will be different according to the nature of the variable of the circuit. For example, with inductance and resistance in parallel with pure capacity,

the relationship which holds between the quantities for maximum impedance of the combination is different according to whether the inductance, capacity or frequency is varied in order to obtain this condition. Hence in most cases it is necessary to consider separately the effect of varying the inductance, the capacity and the frequency. Since $2\pi f = \omega$, where f is the frequency, we shall consider the effect of varying ω instead of f in order to avoid the constant repetition of 2π.

The following symbols will be used :—

I=Current in amperes.
L=Inductance in henries.
R=Resistance in ohms.
b=Susceptance in mhos.
E=Applied E.M.F. in volts.
C=Capacity in farads.
g=Conductance in mhos.
V=Potential difference in volts.

Series Circuits.

The current which flows through a circuit containing inductance, capacity and resistance in series is given by the expression

$$I = \frac{E}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

R being the total resistance of the circuit, however this resistance may be distributed.

Inductance and Capacity in Series without Resistance.

Since the resistance of the circuit is zero the expression for the current reduces to

$$I = \frac{E}{\omega L - \frac{1}{\omega C}}$$

From inspection of this equation it is obvious that the current will be a maximum (in this case infinitely large) when $\omega L = 1/\omega C$, *i.e.*, when the inductive reactance is equal to the capacity reactance, or when $\omega = 1/\sqrt{LC}$ (condition c). Also since the potential difference across the inductance is given by $V_L = \omega LI$, and if I is a maximum, it can be shown that V_L will also be a maximum when $\omega = 1/\sqrt{LC}$ (condition a).

The potential difference across the condenser is given by $I/\omega C$ and this also is a maximum when I is a maximum, *i.e.*, when $\omega L = 1/\omega C$ (condition b). The natural frequency of oscillation of a closed circuit can be obtained from the expression

$$2\pi f = \omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

and if R be negligible this reduces to the form $\omega = 1/\sqrt{LC}$; ω in this case being $2\pi \times$ natural frequency of oscillation. Hence we see that, with a simple series circuit of negligible resistance, when the applied frequency is equal to the natural frequency we have maximum current, maximum potential difference across the inductance, and maximum potential difference across the condenser all occurring simultaneously. We will now investigate the effect of resistance.

Inductance, Capacity and Resistance in Series.

The potential difference across the inductance is given by $V_L = \omega LI$ and substituting the value of I in this expression we obtain

$$V_L = \frac{\omega LE}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

To satisfy condition a this must be a maximum and, as pointed out above, we have to consider separately the effect of inductance, capacity, and frequency variations.

Inductance Variation.

To find the required relationship the simplest method is to differentiate the above expression for V_L with respect to L and equate to zero.

$$V_L^2 = \frac{\omega^2 L^2 E^2}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

differentiating gives

$$2V_L \frac{dV_L}{dL} = \frac{2\omega^2 LE^2\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right] - 2\omega^3 L^2 E\left(\omega L - \frac{1}{\omega C}\right)}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

equating to zero and simplifying we obtain

$$\omega = \frac{1}{\sqrt{LC - R^2C^2}} \quad .. \quad (1)$$

i.e., when $L = \frac{1}{\omega^2 C} + R^2C$

the potential difference across the inductance will be a maximum.

Capacity Variation.

Differentiating the equation for V_L^2 with respect to C, we obtain—

$$2V_L \frac{dV_L}{dC} = \frac{-2\omega^2L^2E^2\left(\omega L - \frac{1}{\omega C}\right)\left(\frac{1}{\omega C^2}\right)}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

Equating to zero and simplifying gives

$$\omega = \frac{1}{\sqrt{LC}} \quad .. \quad .. \quad (2)$$

Hence when $C = 1/\omega^2 L$ the potential difference across the inductance will be a maximum.

Frequency Variation.

Differentiating the equation for V_L^2 with respect to ω we obtain—

$$2V_L \frac{dV_L}{d\omega} = \frac{2\omega L^2E^2\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right] - 2\left(\omega L - \frac{1}{\omega C}\right)\left(L + \frac{1}{\omega^2 C}\right)\omega^2L^2E^2}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

equating to zero gives—

$$R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2 = \left(\omega L - \frac{1}{\omega C}\right)\left(\omega L + \frac{1}{\omega C}\right)$$

from which

$$\omega = \frac{1}{\sqrt{LC - \frac{C^2R^2}{2}}} \quad .. \quad (3)$$

and this value of ω will be found to make V_L a maximum.

To satisfy condition *b*, *i.e.*, to obtain maximum potential difference across the capacity, we next must proceed in exactly the same way as before. The potential difference at the terminals of a condenser is given by the expression $V_C = I/\omega C$ and substituting the value of I we obtain

$$V_C = \frac{E}{\omega C\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

and

$$V_C{}^2 = \frac{E^2}{\omega^2C^2\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]}$$

Inductance Variation.

Differentiating with respect to L gives

$$2V_C\frac{dV_C}{dL} = \frac{-E^2(2\omega^4C^2L - 2\omega^2C)}{\omega^4C^4\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

Equating to zero and solving we get

$$\omega = \frac{1}{\sqrt{LC}} \quad .. \quad (4)$$

i.e., the potential difference at the terminals of the condenser is greatest when $L = 1/\omega^2 C$.

Capacity Variation.

Differentiating with respect to C gives

$$2V_C\frac{dV_C}{dC} = \frac{-E^2(2\omega^2CR^2 + 2\omega^4L^2C - 2L\omega^2)}{\omega^4C^4\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

Equating to zero and solving we get

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}} \quad .. \quad (5)$$

i.e., when $C = \frac{1}{\omega^2 C^2 + R^2}$

the potential difference at the terminals of the condenser is greatest.

Frequency Variation.

Differentiating with respect to ω gives

$$2V_C\frac{dV_C}{d\omega} = \frac{-E^2(2\omega C^2R^2 + 4\omega^3L^2C^2 - 4LC\omega)}{\omega^4C^4\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

Equating to zero and solving we get

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{2L^2}} \quad .. \quad (6)$$

and this value for ω will be found to give the maximum potential difference at the terminals of the condenser.

To satisfy condition c, *i.e.*, to obtain maximum current, it is obvious that the expression for the impedance, *i.e.*,

$$\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

must be a minimum; since R is constant this expression will be a minimum when

$$\omega L = 1/\omega C \text{ or when } \omega = \frac{1}{\sqrt{LC}} \qquad (7)$$

and this will be so whether we vary L, C or ω.

Inductance with Included Resistance in Series with Capacity.

Since in this case the inductance has a resistance R, the potential difference at its terminals when a current I flows through it is given by

$$V_L = I\sqrt{R^2 + \omega^2 L^2}$$

and substituting the value of I gives

$$V_L = \frac{E\sqrt{R^2 + \omega^2 L^2}}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}}$$

or
$$V_L^2 = \frac{E^2 (R^2 + \omega^2 L^2)}{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

and to satisfy condition a, V_L must be a maximum.

Inductance Variation.

Differentiating with respect to L gives

$$2V_L \frac{dV_L}{dL} = \frac{-2E^2R^2\left(\omega L - \frac{1}{\omega C}\right)\omega + 2E^2\omega^2 L\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right] - 2\omega^3 E^2 L^2\left(\omega L - \frac{1}{\omega C}\right)}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

Equating to zero we have

$$\omega^2 L\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]$$
$$= \omega R^2\left(\omega L - \frac{1}{\omega C}\right) + L^2\omega^3\left(\omega L - \frac{1}{\omega C}\right)$$

from which $\omega^2 CL^2 - L - R^2 C = 0$,

and hence $$\omega = \sqrt{\frac{1}{LC} + \frac{R^2}{L^2}} \qquad .. \quad (8)$$

i.e., the potential difference at the terminals of the inductance has a maximum value when

$$L = \frac{1 + \sqrt{1 + 4R^2C^2\omega^2}}{2\omega^2 C}$$

Capacity Variation.

Differentiating with respect to C gives

$$2V_L \frac{dV_L}{dC} = \frac{-2\left(\omega L - \frac{1}{\omega C}\right)\left(\frac{1}{\omega C^2}\right)}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

Equating to zero and solving we have,

$$\omega = \frac{1}{\sqrt{LC}} \qquad .. \qquad .. \quad (9)$$

Thus it will be found that V_L will be a maximum when $C = 1/\omega L^2$.

Frequency Variation.

Differentiating with respect to ω gives

$$2V_L \frac{dV_L}{d\omega} = \frac{-2E^2R^2\left(\omega L - \frac{1}{\omega C}\right)\left(L + \frac{1}{\omega^2 C}\right) + 2E^2\omega L^2\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right] - 2E^2\omega^2 L^2\left(\omega L - \frac{1}{\omega C}\right)\left(L + \frac{1}{\omega^2 C}\right)}{\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right]^2}$$

Equating to zero we have

$$\omega L^2\left[R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2\right] = R^2\left(\omega L - \frac{1}{\omega C}\right)\left(L + \frac{1}{\omega^2 C}\right) + \omega^2 L^2\left(\omega L - \frac{1}{\omega C}\right)\left(L + \frac{1}{\omega^2 C}\right)$$

which when simplified becomes—

$$2\omega^4 L^3 C - 2\omega^3 L^2 - R^2 = 0$$

from which

$$\omega^2 = \frac{L + \sqrt{L^2 + 2CLR^2}}{2L^2 C},$$

since only the positive value for ω^2 is admissible, and therefore

$$\omega = \left[L + \frac{\sqrt{L^2 + 2CLR^2}}{2L^2 C}\right]^{\frac{1}{2}} \qquad (10)$$

The relationship which must hold between the quantities to satisfy conditions *b* and *c* are given by equations (4), (5), (6) and (7), since the fact that the resistance is now integral with the inductance does not in any way affect the equation for the potential difference at the terminals of the condenser; neither does it affect the expression for the current through the circuit.

The treatment of the parallel circuits is slightly more complex. To satisfy condition *d* we require the equivalent reactance of the circuit to be zero. By equivalent reactance is meant the reactance of the series circuit which is electrically equivalent to the parallel circuit. Strictly speaking no series circuit can be the exact equivalent of a parallel circuit in all respects, but for deducing certain results it is convenient to resolve the parallel circuit into an "equivalent" series circuit. For example, if we make the equivalent reactance zero, the parallel circuit exhibits only resistance, that is to say, any current which flows from the applied source through the combination is in phase with the E.M.F.

Parallel Circuits

The method of treatment will be more clearly understood if we consider the simplest parallel circuit.

Pure Inductance in Parallel with Pure Capacity.

In order to satisfy condition *d* it will first be necessary to resolve this circuit into an equivalent series circuit. In dealing with series circuits we add reactances; thus in a series circuit consisting of inductances L_1, L_2, L_3, and capacities C_1, C_2, the total reactance is

$$\omega L_1+\omega L_2+\omega L_3-\frac{1}{\omega C_1}-\frac{1}{\omega C_2}$$

capacity reactance being considered negative. If the circuit also contains resistances R_1, R_2, R_3, the total resistance of this series circuit is $R_1+R_2+R_3$. Thus we are enabled to solve the circuit. For parallel circuits we must deal with other quantities called susceptance and conductance. Susceptance is defined as being $-X/Z^2$ where X is reactance and Z is impedance. Due to the presence of the minus sign it will be seen that capacity-susceptance will be positive and inductive-susceptance negative. Conductance is defined as being R/Z^2. For our parallel circuit therefore we must determine the conductance and susceptance for each branch, and since conductances and susceptances may be added algebraically we determine the total conductance and total susceptance of the circuit by adding the separate conductances and susceptances. Let G be the total conductance and B the total susceptance of a parallel circuit, then the reactance of the equivalent series circuit can be shown to be $-B/(G^2+B^2)$, and the resistance of the equivalent series circuit $G/(G^2+B^2)$. Since we merely require the equivalent reactance to be zero, *i.e.*, we require $-B/(G^2+B^2)$ to be zero, it will be sufficient for our purpose to determine B, the total susceptance and equate it to zero.

The impedance Z_L of the branch containing the inductance

$$=\omega L,$$

$$\therefore \quad Z_L^2=\omega^2 L^2.$$

The reactance X_C of the branch containing the inductance $=\omega L$,

$\therefore$ the susceptance b_L of this branch

$$=\frac{-X_L}{Z_L^2}=\frac{-\omega L}{\omega^2 L^2}=-\frac{1}{\omega L}$$

The impedance Z_C of the branch containing the capacity

$$=\frac{1}{\omega C}$$

$$\therefore \quad Z_C^2=\frac{1}{\omega^2 C^2}$$

The reactance X_C of the branch containing the capacity $=-1/\omega C$

$\therefore$ the susceptance b_C of this branch

$$=\frac{-X_C}{Z_C^2}=\frac{-(-1/\omega C)}{1/\omega^2 C^2}=\omega C$$

The total susceptance therefore

$$=B=b_L+b_C=\omega C-1/\omega L,$$

and this is to be zero.

Hence the required condition is satisfied when

$$\omega C=1/\omega L,$$

or

$$\omega=\frac{1}{\sqrt{LC}} \quad .. \quad (11)$$

and this result will obviously be obtained whichever of the quantities L, C, or ω be varied in order to satisfy the condition.

To satisfy condition e we require the impedance of the circuit to be a maximum. Now the impedance of the parallel circuit, considered as a whole, is given by the expression $1/(G^2+B^2)$. Also, since the resistance in each arm of the circuit is zero, the conductance of each arm, and therefore the total conductance, is zero; *i.e.*, $G=0$. When $\omega = 1/\sqrt{LC}$ we have seen that B is also zero, therefore it follows that when ω has this value the impedance of the circuit is infinitely great. Thus the required condition is satisfied when

$$\omega = 1/\sqrt{LC} \quad \ldots \quad \ldots \quad (12)$$

This circuit is, of course, that of the rejector type wave-trap.

Inductance and Resistance in Parallel with Pure Capacity.

Condition d, equivalent reactance to be zero.

The impedance Z_L of the branch containing the inductance

$$= \sqrt{R^2+\omega^2L^2} \quad \therefore \quad Z_L{}^2 = R^2+\omega^2L^2.$$

The reactance X_L of the branch containing the inductance $=\omega L$. Therefore the susceptance b_L of this branch

$$= \frac{-X_L}{Z_L{}^2} = -\frac{\omega L}{R^2+\omega^2L^2}$$

The impedance Z_C of the branch containing the capacity

$$= 1/\omega C \quad \therefore \quad Z_C{}^2 = 1/\omega^2C^2$$

The reactance X_C of the branch containing the capacity $=-1/\omega C$. Therefore the susceptance b_C of this branch

$$= \frac{-X_C}{Z_C{}^2} = \frac{-(-1/\omega C)}{1/\omega^2C^2} = \omega C$$

Hence the total susceptance

$$= B = \omega C - \frac{\omega L}{R^2+\omega^2L^2}$$

and equating this to zero we have

$$\omega C = \frac{\omega L}{R^2+\omega^2L^2}$$

from which the value of ω to satisfy the required condition is found to be

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}} \quad \ldots \quad (13)$$

Solving this equation for L we find

$$L = \frac{1 \pm \sqrt{1 - 4\,\omega^2C^2R^2}}{2\,\omega^2 C}$$

thus if $4\,\omega^2C^2R^2 < 1$, there will be two values of L which satisfy the required condition.

Condition e, impedance to be a maximum.

Now the impedance is given by

$$\frac{1}{\sqrt{G^2+B^2}}$$

and we therefore require

$$\sqrt{G^2+B^2}$$

to be a minimum. This quantity,

$$\sqrt{G^2+B^2}$$

is called the admittance of the circuit and is usually denoted by Y. We have already derived an expression for B, and found it equal to

$$\omega C - \frac{\omega L}{R^2+\omega^2L^2}$$

We must now determine G.

The conductance g_L of the branch containing the inductance

$$= \frac{R}{Z_L{}^2} = \frac{R}{R^2+\omega^2L^2}$$

The conductance g_C of the branch containing the capacity $=0$, since the resistance in this branch $=0$.

Therefore the total conductance

$$= G = \frac{R}{R^2+\omega^2L^2}$$

Hence the admittance

$$= Y = \sqrt{G^2+B^2}$$

$$= \sqrt{\left(\frac{R}{R^2+\omega^2L^2}\right)^2 + \left(\omega C - \frac{\omega L}{R^2+\omega^2L^2}\right)^2}$$

$$\text{or } Y^2 = \left(\frac{R}{R^2+\omega^2L^2}\right)^2 + \left(\omega C - \frac{\omega L}{R^2+\omega^2L^2}\right)^2$$

Inductance Variation.

Differentiating the above expression with respect to L gives—

$$2Y\frac{dY}{dL} = 2\left[\frac{R}{R^2+\omega^2L^2}\right]\left[\frac{-2R\omega^2L}{(R^2+\omega^2L^2)^2}\right]$$
$$+2\left[\omega C - \frac{\omega L}{R^2+\omega^2L^2}\right]$$
$$\left[\frac{-\omega(R^2+\omega^2L^2)+2\omega^3L^2}{(R^2+\omega^2L^2)^2}\right]$$

$$= \frac{[2\omega C\,(R^2+\omega^2L^2) - 2\omega L]\,[2\omega^3L^2 - \omega\,(R^2+\omega^2L^2)] - 4R^2\omega^2L}{(R^2+\omega^2L^2)^3}$$

Equating this to zero, we have—

$$2\omega^4L^2CR^2 + 2\omega^6L^4C - 2\omega^4L^3 - 4\omega^2CR^4 - 2\omega^2LR^2 = 0$$

or

$$\omega^4CL^4 - \omega^2L^3 - (LR^2 + CR^4) = 0$$

from which

$$\omega^2 = \frac{1}{LC} + \frac{R^2}{L^2}$$

and hence

$$\omega = \sqrt{\frac{1}{LC} + \frac{R^2}{L^2}} \quad .. \quad (14)$$

Thus when

$$L = \frac{1 + \sqrt{1 + 4R^2C^2\omega^2}}{2\omega^2C}$$

it will be found that the admittance is a minimum or the impedance a maximum.

Capacity Variation.

Differentiating the expression for Y^2 with respect to C gives—

$$2Y\frac{dY}{dC} = 2\omega\left[\omega C - \frac{\omega L}{R^2 + \omega^2L^2}\right]$$

equating to zero and simplifying we have—

$$C\omega^2L^2 + CR^2 - L = 0$$

from which

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}} \quad .. \quad (15)$$

i.e., when

$$C = \frac{L}{\omega^2L^2 + R^2}$$

the impedance is a maximum.

Frequency Variation.

Differentiating the expression for Y^2 with respect to ω gives—

$$2Y\frac{dY}{d\omega} = 2\left[\frac{R}{R^2 + \omega^2L^2}\right]\left[\frac{-2\omega L^2R}{(R^2 + \omega^2L^2)^2}\right] + 2\left[\omega C - \frac{\omega L}{R^2 + \omega^2L^2}\right]\left[C - \frac{[L(R^2 + \omega^2L^2) - 2\omega^2L^3]}{[R^2 + \omega^2L^2]^2}\right]$$

Equating to zero, and multiplying through by $(R^2 + \omega^2L^2)^3$ we have—

$$[\omega C(R^2 + \omega^2L^2) - \omega L]\,[C(R^2 + \omega^2L^2)^2 - L(R^2 + \omega^2L^2) + 2\omega^2L^3] - 2R^2\omega L^2 = 0.$$

Multiplying out

$$\omega^6C^2L^6 + 3\omega^4L^4C^2R^2 + 3\omega^2C^2R^4L^2 - 2\omega^2CR^2L^3 - \omega^2L^4 + C^2R^6 - 2CR^4L - R^2L^2 = 0$$

i.e., $(\omega^2L^2 + R^2)\,(\omega^4C^2L^4 + 2\omega^2C^2R^2L^2 + C^2R^4 - L^2 - 2CLR^2) = 0.$

Hence, $\omega^4C^2L^4 + 2\omega^2C^2R^2L^2 + (C^2R^4 - L^2 - 2CLR^2) = 0$

from which

$$\omega^2 = \frac{-CR^2 + \sqrt{L^2 + 2LCR^2}}{L^2C} \quad .. \quad (16)$$

If R be put equal to zero, the equation reduces to 12.

Inductance and Resistance in Parallel with Capacity and Resistance.

Condition d, equivalent reactance to be zero.

The susceptance of the branch containing the inductance

$$= \frac{-\omega L}{R_L^2 + \omega^2L^2}$$

where R_L is the resistance in this branch.

The susceptance of the branch containing the capacity

$$= \frac{1/\omega C}{R_C^2 + \frac{1}{\omega^2C^2}}$$

where R_C is the resistance in this branch.

Therefore, the total susceptance

$$= \frac{1/\omega C}{R_C^2 + \frac{1}{\omega^2C^2}} - \frac{\omega L}{R_L^2 + \omega^2L^2}$$

and this is to be zero, *i.e.*,

$$\frac{1/\omega C}{R_C^2 + \frac{1}{\omega^2C^2}} = \frac{\omega L}{R_L^2 + \omega^2L^2}$$

or $\omega C(R_L^2 + \omega^2L^2) = \omega L(\omega^2C^2R_C^2 + 1)$

from which

$$\omega^2 = \frac{L - CR_L^2}{CL^2 - C^2LR_C^2} \quad .. \quad (17)$$

Equation 13 is obtained from this general expression by putting $R_c = 0$. It is interesting to note that if the time constants of the two branches are equal and also the resistances [*i.e.* if $R_C = R_L = \sqrt{L/C}$] the reactance is independent of frequency and equal to zero.

Condition e, impedance to be a maximum. The total conductance of this circuit

$$= \frac{R_L}{R_L^2 + \omega^2L^2} + \frac{R_C}{R_C^2 + \frac{1}{\omega^2C^2}}$$

hence,

$$Y^2 = G^2 + B^2 = \left[\frac{R_L}{R_L^2+\omega^2L^2} + \frac{R_C}{R_C^2+\frac{1}{\omega^2C^2}}\right]^2 + \left[\frac{1/\omega C}{R_C^2+\frac{1}{\omega^2C^2}} - \frac{\omega L}{R_L^2+\omega^2L^2}\right]^2$$

Write

A for $R_L^2+\omega^2L^2$ and D for $R_C^2+\frac{1}{\omega^2C^2}$.

Then

$$Y^2 = \left[\frac{R_L}{A}+\frac{R_C}{D}\right]^2 + \left[\frac{1/\omega C}{D}-\frac{\omega L}{A}\right]^2$$
$$= \frac{1}{A}+\frac{1}{D}+\frac{2R_LR_C}{AD}-\frac{2L/C}{AD}$$

and this expression is to be a minimum.

Inductance Variation.

Differentiating the given expression with respect to L gives—

$$2Y\frac{dY}{dL} = -\frac{dA/dL}{A^2} - \frac{dD/dL}{D^2} - \frac{\left[2R_LR_CA\frac{dD}{dL}+2R_LR_CD\frac{dA}{dL}\right]}{A^2D^2} - \frac{\left[\frac{2AD}{C}-\frac{2LA}{C}\cdot\frac{dD}{dL}-\frac{2LD}{C}\cdot\frac{dA}{dL}\right]}{A^2D^2}$$

since D does not contain L, $\frac{dD}{dL}=0$.

Hence equating to zero and multiplying through by A^2D we have—

$$-\frac{dA}{dL}D - 2R_LR_C\frac{dA}{dL} - \frac{2A}{C} + \frac{2L}{C}\frac{dA}{dL} = 0$$
$$dA/dL = 2\omega^2L$$
$$\therefore \quad 2\omega^2L\left(\frac{2L}{C}-2R_LR_C-R_C^2-\frac{1}{\omega^2C^2}\right) - \frac{R_L}{C} - \frac{\omega^2L^2}{C} = 0$$

and simplifying

$$\omega^2(L^2C - 2R_LR_CLC^2 - LC^2R_C^2) = L + R_L^2C$$

from which

$$\omega^2 = \frac{L+R_L^2C}{LC(L-2R_LR_CC-CR_C^2)} \quad \ldots \quad (18)$$

i.e., the real value of L which satisfies the above equation will be found to make the impedance a maximum.

Capacity Variation.

Differentiating the given expression with respect to C gives—

$$2Y\frac{dY}{dC} = -\frac{dA/dC}{A^2} - \frac{dD/dC}{D^2} - \frac{\left[2R_LR_CA\frac{dD}{dC}+2R_LR_CD\frac{dA}{dC}\right]}{A^2D^2} - \frac{\left[-\frac{2LAD}{C^2}-\frac{2LA}{C}\cdot\frac{dD}{dC}-\frac{2LD}{C}\cdot\frac{dA}{dC}\right]}{A^2D^2}$$

Since A does not contain C, $dA/dC=0$. Hence equating to zero and multiplying through by AD^2 we have :—

$$-\frac{dD}{dC}A - 2R_LR_C\frac{dD}{dC} + \frac{2LD}{C^2} + \frac{2L}{C}\cdot\frac{dD}{dC} = 0.$$
$$\frac{dD}{dC} = -\frac{2}{\omega^2C^3}$$
$$\therefore \quad \frac{2}{\omega^2C^3}\left(2R_LR_C+R_L^2+\omega^2L^2-\frac{2L}{C}\right) + \frac{2L}{C^2}\left(R_C^2+\frac{1}{\omega^2C^2}\right) = 0.$$

Multiplying out and simplifying

$$\omega^2(L^2C + LR_C^2C^2) = L - 2R_LR_CC - R_L^2C$$

from which

$$\omega^2 = \frac{L-2R_LR_CC-R_L^2C}{L^2C+LR_C^2C^2} \quad \ldots \quad \ldots \quad (19)$$

Frequency Variation.

The expression for the frequency which makes the impedance a maximum is rather clumsy but is given for the sake of completeness.

Differentiating the expression for Y^2 with respect to ω gives—

$$2Y\frac{dY}{d\omega} = -\frac{dA/d\omega}{A^2} - \frac{dD/d\omega}{D^2} - \frac{\left[2R_LR_C\frac{dA}{d\omega}D+2R_LR_C\frac{dD}{d\omega}A\right]}{A^2D^2} + \frac{\frac{2LA}{C}\cdot\frac{dD}{d\omega}+\frac{2LD}{C}\cdot\frac{dA}{d\omega}}{A^2D^2}$$

equating to zero and multiplying through by A^2D^2

$$\frac{dD}{d\omega}\left(\frac{2LA}{C}-2R_LR_CA-A^2\right)+$$
$$+\frac{dA}{d\omega}\left(\frac{2LD}{C}-2R_LR_CD-D^2\right)=0.$$

Now $\dfrac{dA}{d\omega}=2\omega L^2$ and $\dfrac{dD}{d\omega}=-\dfrac{2}{\omega^3C^2}$.

Substituting these values in the expression, multiplying out and simplifying, we have—

$$\omega^4L^2C^2(L^2-C^2R_C^4-2R_LR_C^3C^2+2LCR_C^2)$$
$$+2\omega^2L^2C^2(R_L^2-R_C^2)$$
$$+R_L^4C^2+2R_L^3R_CC^2-2LR_L^2C-L^2=0 \quad (20)$$

The value of ω can be found in any particular case, but the general expression above does not admit of further simplification.

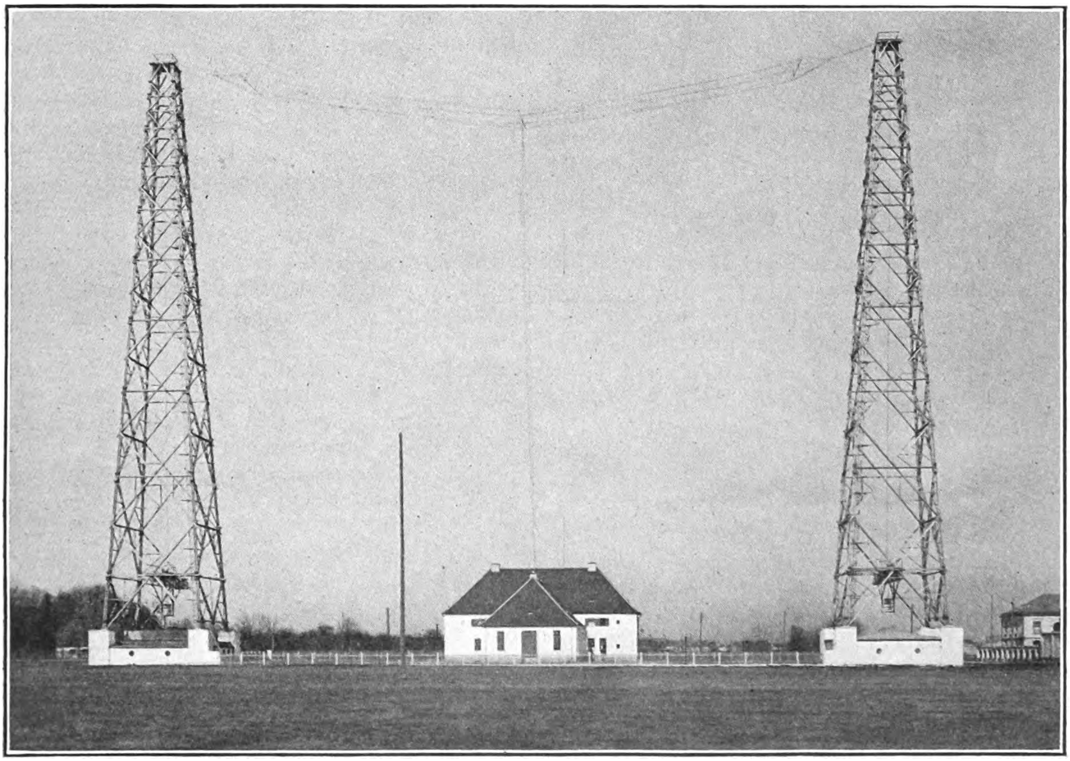
An interesting special case is when

$$R_L=R_C=\sqrt{L/C}.$$

With this value of resistance in each arm, the differential coefficient of the admittance with respect to ω is equal to zero. This means that the admittance, and consequently the current, is independent of the frequency.

It is hoped that the results deduced, and the method of analysis of these more elementary circuits will prove of use to those who are not already familiar with the subject.

Münich Broadcasting Station.



An interesting photograph which shows the wooden lattice aerial masts of the Münich Broadcasting Station, and the house which contains the transmitting apparatus and provides quarters for the permanent staff.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 612 *of October issue.*)

PART IV.

APPLICATIONS TO ELECTRICAL PROBLEMS.

1. The Fundamental Laws of Current Networks.

THE whole theory of electric current networks, whatever be the nature of the conducting elements of the networks or of the currents flowing in them, is based on two remarkable generalisations known as Kirchhoff's first and second laws—remarkable because of their almost axiomatic simplicity and the wealth of information and deduction derivable from their application.

The first law—the algebraic sum of the currents which meet at any point in a network of conductors is zero.

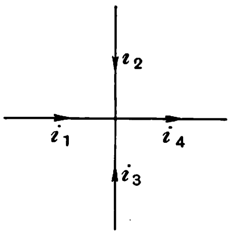


Fig. 36.

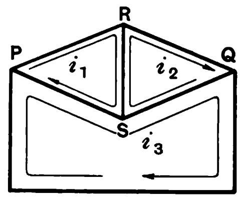


Fig. 37.

Notice the word "algebraic," which here, as always, means that sign must be taken into account. By "sign" is meant the sense of the current relative to the point considered. The usual convention in this matter is that a current will be reckoned positive if it is flowing towards the point, and negative if it is flowing away from the point. Thus the application of the law to the element of a network shown in Fig. 36 leads to the equation—

$$i_1 + i_2 + i_3 - i_4 = 0.$$

"But," says the reader, "how can I tell, in the case of a really complicated network, which way the currents are flowing?" The answer is: "You can't, but it doesn't matter." Not that a special guardian angel has been detailed for this job, but that the combination of correct analysis with known data (such as the nature and disposition of the acting electromotive forces) will automatically confirm or correct the assigned directions. Thus, if in the above example the current i_2 is in fact flowing away from the point, its evaluation will lead to a negative number -10, for instance, showing that it is a current of magnitude 10 flowing in a direction opposite to that indicated.

An alternative and preferable manner of representing the flow of current in a network is that illustrated in Fig. 37, where the actual currents are regarded as due to the superposition of the circuital currents shown. Thus the current in PR is i_1, in RQ i_2, and in RS $(i_1 \sim i_2)$. This form of representation saves the writing of several current equations, for it actually assumes and embodies the first law. The sum of the currents meeting at the point R, for instance, is $i_1 - i_2 - (i_1 - i_2)$, *i.e.*, 0.

Physically, the law states that there is no accumulation of electricity at any meeting point of conductors in a network. In point of actual fact, there will be local accumulations of electricity for an exceedingly short period after a circuit has been closed, just as water released into a system of pipes will first fill up the pipes before settling down to a steady flow, but in general this initial period will be negligibly short in duration, and the law applies exactly to the final steady state.

Kirchhoff's second law relates to the potential differences in a closed circuit. The term "potential difference" includes both "electromotive force," *i.e.*, a chemically or mechanically maintained potential difference which supplies energy to a circuit, and "back E.M.F." or fall of potential due to the passage of a current in a conductor. Consider, for instance, the passage of a current of magnitude i through a resistance R ohms, illustrated in Fig. 38. By Ohm's

law, a knowledge of which is assumed, the magnitude of the potential difference between the points a and b is iR volts, and the current flows "downhill," as one would expect it to. That is, a is at a higher potential than b. If the conductor R were removed and the terminals a and b maintained at the same potentials as before, a current would obviously tend to flow round the rest of the circuit in the direction shown by the dotted line, *i.e.*, in a direction opposite

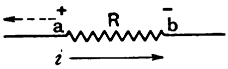


Fig. 38.

to that of the original current. Thus, if the direction of the current through the resistance be taken as positive, the appropriate sign to attribute to the potential difference iR is negative. Conversely, any potential difference in the closed circuit containing R which would tend to maintain the current in the same—*i.e.*, positive—direction can reasonably be given a positive sign. Allocating signs in this manner, one can form the algebraic sum of all the potential differences in any closed circuit, and Kirchhoff's second law states that this sum is zero. There should be no difficulty in appreciating the physical significance of the second law, for it means no more than this—that a man who sets out from his home on a roundabout journey up hill and down dale, and then comes home again, must of necessity in the course of his wanderings have gone uphill

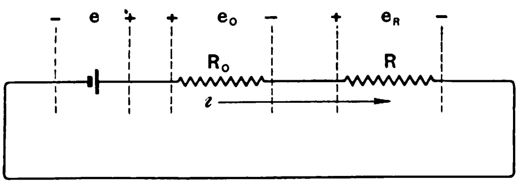


Fig. 39.

and downhill to exactly the same extent, since he has finished up at the level from which he started.

Applying the law by way of illustration to the circuit shown in Fig. 39, which represents a battery of E.M.F. e volts and internal resistance R_0 ohms supplying current to a resistance R ohms, we have—

$$e + e_0 + e_R = 0$$

i.e.,
$$e - iR_0 - iR = 0$$
or
$$i = e/(R_0 + R)$$

In the case of a varying current, *e.g.*, the high-frequency sine wave alternating current of wireless telegraphy, other "back E.M.F.s," or opposing potential differences, will come into play in addition to those due to the resistances of the conductors involved. It must be assumed that these ideas are already familiar to the reader, but a brief statement of them will be given for the sake of completeness.

2. Inductance.

A pure inductance opposes to a varying current i a back E.M.F. e_L proportional to the rate of change of the current, *i.e.*, proportional to di/dt. The definition of the unit of inductance is so chosen that the back E.M.F. in volts is $L(di/dt)$, L being the inductance in henries. A negative sign is attributed to it for the same reason as in the case of a pure resistance.

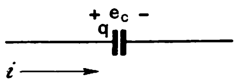


Fig. 40.

3. Capacity.

A pure capacity in a circuit carrying a varying current i (see Fig. 40) will oppose to the current a back E.M.F. proportional to the quantity of electricity stored in the condenser. The definition of the unit of capacity is so chosen that this back E.M.F. in volts is q/C, C being the capacity in farads, and q the quantity of electricity in coulombs stored on the positive electrode of the condenser, *i.e.*, leaving the matter of sign for the present—

$$|e_C| = q/C$$

Now, since the rate of change of q (*i.e.*, dq/dt) is the rate of flow of electricity along the conductor, *i.e.*, i amperes (or i coulombs per sec.), we have—

$$i = dq/dt$$

Therefore—

$$\frac{d|e_C|}{dt} = \frac{d}{dt}\left(\frac{q}{C}\right) = \frac{1}{C}\frac{dq}{dt} = \frac{i}{C}$$

Since the direction of the potential difference e_c relative to that of the current is such as to oppose the current, a negative sign is attributed to it in the above equation, giving—

$$\frac{de_c}{dt} = -\frac{i}{C}$$

4. Vectorial Representation of Back E.M.F.s.

It was shown in Para. 11, Part II (June, 1927), that a sine wave alternating current can be represented in the form

$$\mathbf{i}\cdot\nu = \hat{\imath} \cos \omega t$$

where $\mathbf{i}$ is a vector of constant magnitude $\hat{\imath}$, rotating with constant angular velocity, and where ν is a constant unit vector of

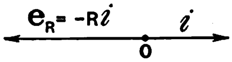


Fig. 41.

reference parallel to the bottom edge of the paper. (In the writer's opinion, this form of statement is preferable to the more usual description of the instantaneous value of the current as the "projection" on a given time axis of the rotating vector, since it permits the relationship between the vector and the current to be stated as an exact equation, as above).

(*a*) If such a current flows through a resistance R ohms, the back E.M.F. e_R is given, as already shown, by

$$e_R = -Ri$$

and since e_R is thus a simple multiple of i it will of necessity be a sine wave alternating potential difference of the same frequency as i, and can therefore be represented by a rotating vector $\mathbf{e}_R$ in the same manner. Expressing both the current and the back E.M.F. in vector form, we have

$$\mathbf{e}_R\cdot\nu = -R(\mathbf{i}\cdot\nu) = -R\mathbf{i}\cdot\nu$$

This can be put in the form

$$(\mathbf{e}_R + R\mathbf{i})\cdot\nu = 0$$

Since this is true at every instant, it follows that the vector $(\mathbf{e}_R + R\mathbf{i})$ is either zero at every instant or else is perpendicular to ν at every instant. The second condition is obviously not fulfilled. Therefore

$$\mathbf{e}_R + R\mathbf{i} = 0 \quad \text{or} \quad \mathbf{e}_R = -R\mathbf{i}$$

This shows that the vector representing e_R is R times $\mathbf{i}$ in magnitude and opposite to it in direction, as in Fig. 41.

(*b*) For the back E.M.F. generated in a pure inductance L we have

$$\mathbf{e}_L = -L(di/dt)$$

and since the differential coefficient of a sine wave is a sine wave (or a cosine wave, which comes to the same thing) of the same frequency it follows that e_L can also be represented by a rotating vector of the same angular velocity as $\mathbf{i}$. Hence we have the scalar product equation

$$\mathbf{e}_L\cdot\nu = -L\frac{d(\mathbf{i}\cdot\nu)}{dt}$$

Now it is easy to show (see Appendix I) that as ν is a constant vector

$$\frac{d(\mathbf{i}\cdot\nu)}{dt} = \frac{d\mathbf{i}}{dt}\cdot\nu$$

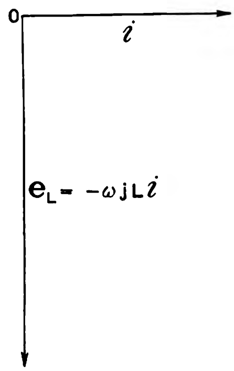
Further, it has been shown (see Para. 12, Part III, October, 1927) that for a vector of this character

$$d\mathbf{i}/dt = \omega j\mathbf{i}$$

Therefore

$$\mathbf{e}_L\cdot\nu = -\omega jL\mathbf{i}\cdot\nu$$

whence, as in case (*a*), $\mathbf{e}_L = -\omega jL\mathbf{i}$. The relation between the vectors $\mathbf{e}_L$ and $\mathbf{i}$ is therefore as shown in Fig. 42.



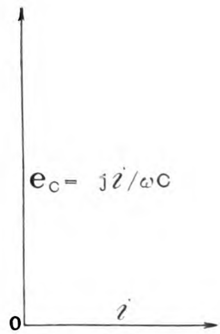


Fig. 42. Fig. 43.

(*c*) With the above two examples the reader should have no difficulty in showing that the vector representing the back E.M.F. due to a condenser of capacity C is given by

$$\omega j\mathbf{e}_c = -\mathbf{i}C$$

i.e.,

$$\mathbf{e}_c = -\mathbf{i}/\omega jC$$

This is illustrated in Fig. 43.

5. The Vector Analysis of Alternating Current Circuits.

It was shown in Para. 11, Part II (June, 1927), that Kirchhoff's law relating to the zero sum of currents meeting at a point in a network is equally true of the vectors used to represent any such set of alternating currents of the same frequency. Further, it will be found on reference to the proof there given that it applies also to the zero sum of any number of alternating potential differences of the same frequency. We may therefore say at once that Kirchhoff's first and second laws apply without any modification to the current and potential difference vectors of any single frequency alternating current network. The analysis of any such network is thus reduced to quite elementary vector algebra, in place of the systems of differential equations which arise from the ordinary scalar analysis of such problems.

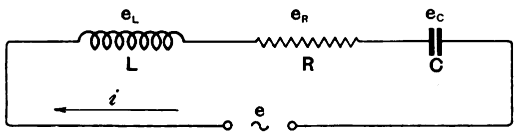


Fig. 44.

Consider, for example, the fundamentally important circuit shown in Fig. 44, *i.e.*, a pure resistance, a pure inductance, and a pure capacity in series with a source of alternating (sine wave) E.M.F., assumed to be of negligible internal resistance. Kirchhoff's second law gives at once the vector equation

$$\mathbf{e} + \mathbf{e}_R + \mathbf{e}_L + \mathbf{e}_C = 0$$

On the instant of closing the circuit certain transient phenomena will occur due to the fact that no system of finite mass (and inductance is the electrical equivalent of mechanical mass) can pass from one equilibrium condition to another instantaneously. This comparatively unimportant aspect of the matter will be considered later. When a steady state has been reached (generally in a fraction of a second) the current flowing in the circuit will be of the same character and frequency as the E.M.F., since no other than a current of this character can give rise to back E.M.F.s which will exactly balance the driving E.M.F. at every instant as required by the above equation. Therefore, assuming the E.M.F. to be

$$\mathbf{e}\cdot\nu = \hat{e} \cos \omega t$$

the current will be of the same frequency $\omega/2\pi$ and can thus be represented by the vector $\mathbf{i}$ of constant magnitude $\hat{\imath}$ and constant angular velocity ω. The above determined expressions for the back E.M.F.s in terms of the current can therefore be substituted in the potential difference equation, giving

$$\mathbf{e} - R\mathbf{i} - j\omega L\mathbf{i} - \frac{\mathbf{i}}{j\omega C} = 0$$

i.e.,

$$\left(R + j\omega L + \frac{1}{j\omega C}\right)\mathbf{i} = \mathbf{e}$$

or

$$\left\{R + j\left(\omega L - \frac{1}{\omega C}\right)\right\}\mathbf{i} = (R + jX)\mathbf{i} = \mathbf{e}$$

where X has been written for $\omega L - 1/\omega C$ for compactness. Thus, finally,

$$\mathbf{i} = \frac{\mathbf{e}}{(R + jX)}$$

This is the complete solution for the "steady state" alternating current in the circuit, and for most analytical purposes is the best form of representing it. It is probably the most important single result in the whole of alternating current theory—at least, as far as wireless telegraphy is concerned—and will therefore be examined in some detail.

In the first place, the scalar form of the solution can be written down at once. It has already been given in Para. 21, Part II (July, 1927). Expressing the operator $(R + jX)$ in the form $Z\epsilon^{j\phi}$, *i.e.*,

$$Z^2 = R^2 + X^2 \quad \text{and} \quad \phi = tan^{-1}\, X/R$$

$$\mathbf{i} = \mathbf{e}/(Z\epsilon^{j\phi}) = \epsilon^{-j\phi}\mathbf{e}/Z$$

The effect of this operator is to divide the magnitude of $\mathbf{e}$ by Z and to rotate it through an angle $-\phi$ in a positive direction, *i.e.*, through an angle ϕ in a negative (clockwise) direction. This is illustrated in Fig. 45. Therefore, since i is given by $\mathbf{i}\cdot\nu$, and since $\mathbf{e}$ is such that $\mathbf{e}\cdot\nu = \hat{e} \cos \omega t$, we have

$$i = \mathbf{i}\cdot\nu = \frac{1}{Z}\epsilon^{-j\phi}\mathbf{e}\cdot\nu = \frac{\hat{e}}{Z} \cos (\omega t - \phi)$$

Alternatively, since

$$\frac{1}{(R + jX)} = \frac{R}{Z^2} - \frac{jX}{Z^2}$$

$$\mathbf{i} = \frac{R}{Z^2}\mathbf{e} - \frac{jX}{Z^2}\mathbf{e}$$

which expresses **i** in terms of its components parallel and perpendicular to **e** (the vectors OC and CA in Fig. 45). The corresponding scalar form is, as shown in the Para. 21 referred to above

$$i = \mathbf{i}\cdot\nu = (R/Z^2)\mathbf{e}\cdot\nu - (X/Z^2)j\mathbf{e}\cdot\nu$$
$$= (R/Z^2)\hat{e}\cos\omega t + (X/Z^2)\hat{e}\sin\omega t$$

The back E.M.F.s corresponding to the current i are as shown by the vectors

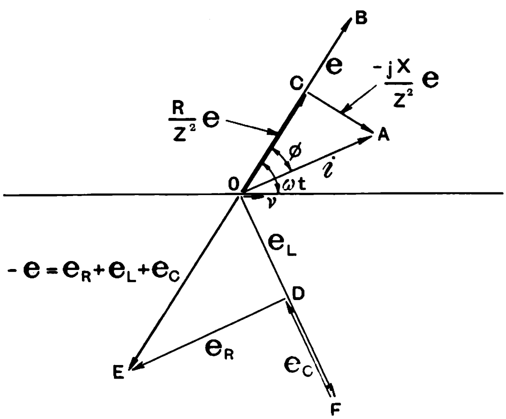


Fig. 45.

OF, FD, DE in Fig. 45. One of the chief advantages of the vector method of analysis is the facility with which the analytical expressions can be translated into pictures, in which form they are much easier to understand.

6. Generalisation and Nomenclature.

The group $(R+jX)$ is known as the "impedance operator" of the circuit. The magnitude of this operator, *i.e.*, Z or $(R^2+X^2)^{\frac{1}{2}}$ is called the "impedance." The angle $\theta = tan^{-1} X/R$ is called the "phase angle" of the impedance since it determines the angle between the current and E.M.F. vectors. The R term is called the resistance component, and the X term the reactance component of the impedance.

In general, the relationship between the current and E.M.F. vectors in any single frequency circuit, however complicated, will be an operator of the form $(R+jX)$. This follows from the fact that any combination of such operators can be represented as some other single operator of the same type. (See Para. 21 referred to above.) The terms defined above are, therefore, given a full generalised interpretation. Thus the R term, however constituted (and it will in most cases contain other than pure resistance terms) will be called the resistance component, and so on.

Some American writers have adopted a still further generalisation of the above nomenclature. The relationship between the current in any given branch of a network and the driving E.M.F. acting in the same or any other branch of the system is called the "transfer impedance" for the specified conditions. The full significance of the above terms will appear more clearly later on, when some rather more complicated systems have been discussed.

7. Impedance Variation.

Returning to the simple series circuit of Fig. 44, we are in practice much concerned with the effect of varying one or other of the component elements of the impedance $(R+jX)$. Notice first that impedance is a circuit characteristic, depending only on the electrical constants of the circuit and the frequency. A circuit is therefore most suitably discussed in terms of its impedance, without reference to any specific E.M.F.

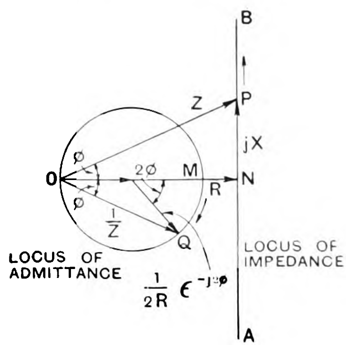


Fig. 46.

The impedance operator can be represented graphically as a vector by assuming the unit vector of reference ν as operand, though the operand need not appear in the analysis or diagrams. The general practice of representing the resistance and reactance components of an impedance by lines parallel to the x and y axes respectively is obviously equivalent to this assumption. On this

basis the impedance $(R+jX)$ can be represented by the line OP in Fig. 46. If now the term X is varied by varying the capacity R, L, and ω remaining constant, the point P will move along the line AB, which can thus be described as the locus of the impedance under the given conditions of variation. The minimum value of Z will clearly correspond to the point N for which X is O. Under these conditions $\mathbf{i}$ will reach its maximum value $\mathbf{e}/R$, the corresponding vector diagram being as shown in Fig. 47.

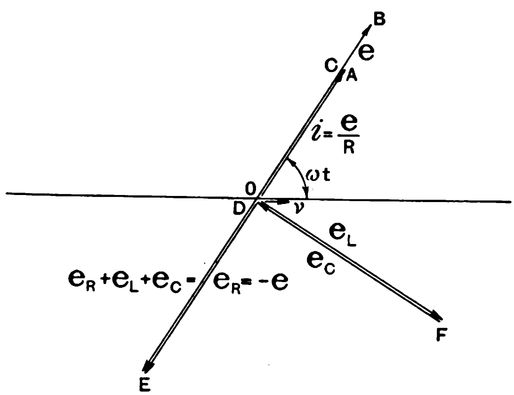


Fig. 47.

This condition is described as the "resonance" of the current in the circuit. In general, a minimum value of the impedance $Z = \sqrt{R^2+X^2}$ will be taken as the criterion of a resonance condition. Notice that in this particular case the resonance is associated with the vanishing of the reactance term, and the current at resonance is in phase with the E.M.F. (*i.e.*, the $\mathbf{i}$ and $\mathbf{e}$ vectors are parallel.) This is not always true of the resonance condition, and is therefore not the proper criterion of resonance.

Since Z is a minimum at resonance the condition can be stated in scalar form

$$dZ/dC = 0$$

with the proviso that the second differential coefficient shall be positive. (See Para. 11, Part III, Sept., 1927.) The reader can easily confirm that this will lead to the same conclusion in the above case—namely,

$$X = \omega L - 1/\omega C = 0$$

or

$$C = 1/\omega^2 L$$

The above describes resonance with respect to condenser variation. If frequency be taken as the variable the condition becomes

$$dZ/d\omega = 0$$

In the present instance the locus of Z is the same for condenser or frequency variation, and the resonance condition is therefore the same, too, *i.e.*,

$$\omega L - 1/\omega C = 0$$

but this again is not always true for the resonance condition, and the particular resonance considered must always be clearly specified.

8. The Current Locus. Circle Diagrams.

The straight line locus for the impedance found in the above simple case is typical of a large number of impedance variations due to variation of one of the magnitudes of the circuit. (In general, variation of the frequency gives rise to a more complicated locus. The loci just happen to be the same in the above case because it is a very simple form of circuit.) It will therefore be of interest to examine the variation of $\mathbf{i}$ in such a case. (This means, of course, the variation of the magnitude and phase of $\mathbf{i}$ relative to $\mathbf{e}$, due to variation of the circuit magnitudes. The variation of i with respect to time is quite another matter, and must be clearly distinguished in the mind.) For the simple series circuit

$$z = R + jX = R(1 + jn)$$

where

$$n = X/R = \tan\phi$$

It will be assumed that R is constant and n variable. The current is given by

$$\mathbf{i} = \frac{\mathbf{e}}{z} = \frac{1}{R}\,\frac{1}{(1+jn)}\,\mathbf{e}$$

It has already been shown that the locus of z is the line AB in Fig. 46. It will now be shown that the locus of $1/z$ is the circle, shown in Fig. 46, *i.e.*, a circle of diameter $1/R$ centre at a distance $1/2R$ from O in the direction ν. By elementary algebra,

$$1/(1+jn) = \tfrac{1}{2}\left\{1 + \frac{1-jn}{1+jn}\right\}$$

and since

$$1 + jn = (1+n^2)^{\frac{1}{2}}\epsilon^{j\phi}$$

and

$$1 - jn = (1+n^2)^{\frac{1}{2}}\epsilon^{-j\phi}$$

$$1/(1+jn)=\frac{1}{2}\left(1+\frac{\sqrt{1+n^2}\,\epsilon^{-j\phi}}{\sqrt{1+n^2}\,\epsilon^{j\phi}}\right)=\frac{1}{2}(1+\epsilon^{-2j\phi})$$

Therefore

$$\frac{1}{z}=\frac{1}{2R}(1+\epsilon^{-2j\phi})=\frac{1}{2R}+\frac{1}{2R}\epsilon^{-2j\phi}$$

and since the line $(1/2R)\epsilon^{-2j\phi}$ as ϕ varies, moves round a circle of radius $1/2R$ as shown in Fig. 46, the proposition is proved. As the end of z moves along AB from N in the direction NB, the end of $1/z$, the reciprocal of the impedance operator, which is sometimes called the "admittance" operator, moves round the circle of diameter $1/R$ from M in the direction MQO. The maximum value of $1/Z$ is obviously $OM=1/R$.

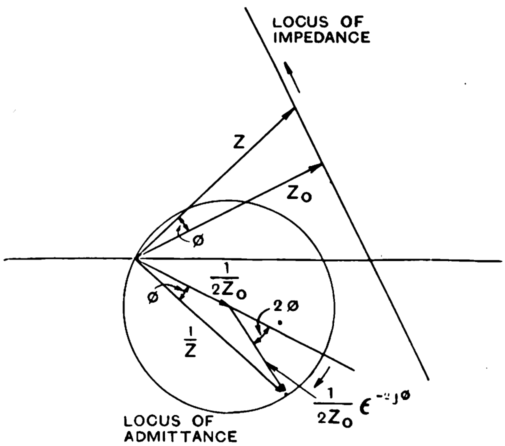


Fig. 48.

The above example is typical of a great number of circuit arrangements met with in wireless practice. In general, any impedance whatever which varies on a straight line locus with variation of one of the circuit magnitudes can be expressed in the form

$$z=z_0(1+jn)$$

where z_0 is not necessarily a resistance term, but may be of the form R_0+jX_0 where R_0 and X_0 are constants. The locus of z is a straight line perpendicular to and at the end of the line representing z_0. The locus of $1/z$ will be the circle $(1/2z)_0\ (1+\epsilon^{-2j\phi})$ where $n=tan\ \phi$. (See Fig. 48.) This is the fundamental basis of the numerous circle diagrams which are met with in alternating current theory, and of which several examples have been described in this journal (*e.g.*, "Simple Resonance Curves and their Modification by Valve Circuits." Prof. E. Mallet, D.Sc., M.I.E.E., February, 1927. Also the series of articles by Dr. Dye on low frequency transformers.)

In all such cases the resonance condition is defined by $n=0$, and the minimum or resonance value of z is z_0.

A representative case of some practical importance is the resonance of the potential difference across the condenser for the series circuit described above. Since

$$\mathbf{e}_c=-\mathbf{i}/j\omega C$$

$$\mathbf{e}_c=-\mathbf{e}/\{j\omega C(R+j\omega L+1/j\omega C)\}$$

i.e.,

$$\mathbf{e}_c=-\mathbf{e}/Z$$

where

$$z=1+j\omega C\,(R+j\omega L)$$

(z can hardly be called an impedance in this case, but it amounts to much the same thing.) The expression of z in the standard form given above for a straight line locus requires a little ingenuity, but is quite easy to follow. Multiplying inside the bracket by $R-j\omega L$ and dividing outside by the same thing,

$$Z=\frac{1}{R-j\omega L}\{R-j\omega L+j\omega C(R^2+\omega^2L^2)\}$$

$$=\frac{R}{R-j\omega L}\left\{1+j\frac{\omega C(R^2+\omega^2L^2)-\omega L}{R}\right\}$$

which is in the standard form $Z_0(1+jn)$ where

$$z_0=R/(R-j\omega L)$$

and is constant with respect to variation of the tuning condenser C, and

$$n=\frac{\omega C(R^2+\omega^2L^2)-\omega L}{R}$$

and is a variable number on account of the variation of C. The locus of z is thus a straight line perpendicular to and at the end of the line representing $R/(R-j\omega L)$. The minimum value of z is therefore

$$z_0=\frac{R}{(R-j\omega L)}=\frac{R(R+j\omega L)}{R^2+\omega^2L^2}$$

the magnitude of which is

$$Z_0 = R/(R^2 + \omega^2L^2)^{\frac{1}{2}} = R/\omega L$$

if R^2 is negligible compared with ω^2L^2, and the resonance value of C is given by $n=0$, *i.e.*,

$$C = L/(R^2 + \omega^2L^2)$$

Notice that the maximum value of the P.D. across the condenser does not correspond exactly with the maximum value of the current in the circuit, an interesting and not generally realised fact. Actually, the difference will only be appreciable if R^2 is appreciable compared with ω^2L^2, which will not generally be the case. However, it is always a possibility. If R is negligible compared with L, the ratio of e_c to e (magnitude), *i.e.*, the ratio of the P.D. across the condenser to the E.M.F. in the circuit, is $\omega L/R$. This quantity is therefore a measure of the magnification of the E.M.F. due to resonance and in wireless applications it is obviously desirable to make this as large as possible. The difference between a good and a bad coil may amount to a stage of amplification. If R is small, as it should be, $\omega L/R$ varies very rapidly with R. This is the reason for the enormous increase in the sensitivity of reception obtainable by means of reaction, which reduces the effective value of R.

APPENDIX I.

Let $\mathbf{r}\cdot\nu = r \cos\theta$, r and θ being functions of t. Then

$$\frac{d(\mathbf{r}\cdot\nu)}{dt} = \cos\theta\frac{dr}{dt} - r\sin\theta\frac{d\theta}{dt}$$

$$= \cos\theta\frac{dr}{dt} + r\cos(\theta + \pi/2)\frac{d\theta}{dt}$$

$$= \frac{(\mathbf{r}\cdot\nu)}{r}\frac{dr}{dt} + (j\mathbf{r}\cdot\nu)\frac{d\theta}{dt}$$

$$= \left(\frac{1}{r}\frac{dr}{dt} + j\frac{d\theta}{dt}\right)\mathbf{r}\cdot\nu$$

$$= \frac{d\mathbf{r}}{dt}\cdot\nu$$

Examples.

1. Referring to the series circuit of Fig. 44,

$L = 100\mu\text{H}$ (*i.e.*, 10^{-4} henries).

$R = 10$ ohms.

$e = 10^{-2} \cos 2\pi \times 830 \times 10^3 t$

Calculate :—

(*a*) The impedance operator corresponding to $C = 1{,}000\ \mu\mu\text{F}$.

(*b*) The instantaneous magnitude of the current in the circuit for this value of the tuning condenser.

(*c*) The magnitude of C which will give the maximum P.D. across the condenser.

(*d*) The ratio of the condenser P.D. to the E.M.F. at resonance.

2. Given that $i = \mathbf{i}\cdot\nu = \hat{\imath}\cos(\omega t - \phi)$ and $e = \mathbf{e}\cdot\nu = \hat{e}\cos\omega t$, show that the mean value of ie from $t=0$ to $t=2\pi/\omega$ is $(\mathbf{i}\cdot\mathbf{e})/2$.

3. Show that for a damped oscillatory current of the form $i = \mathbf{i}\cdot\nu = \hat{\imath}\epsilon^{-kt}\cos\omega t$, the back E.M.F.s due to a resistance R, an inductance L, and a capacity C are given by

$$\mathbf{e}_R = -R\mathbf{i}$$

$$\mathbf{e}_L = -(-k + \omega j)L\mathbf{i}$$

$$\mathbf{e}_C = -\mathbf{i}/(-k + \omega j)C$$

4. Show that the condition $\mathbf{e}_R + \mathbf{e}_L + \mathbf{e}_C = 0$ can be satisfied for the series circuit of Fig. 44 if the current is of the form $i = \hat{\imath}\epsilon^{-kt}\cos\omega t$. Find the values of k and ω in terms of R, L and C.

Answers to Examples in October Issue.

1. $(k + \omega j)\mathbf{v}$; $\{(k^2 - \omega^2) + 2\omega jk\}\mathbf{v}$;
$\sqrt{k^2 + \omega^2}\, v_0\epsilon^{kt}\cos(\omega t + \psi + \tan^{-1}\omega/k)$;
$(k^2 + \omega^2)v_0\epsilon^{kt}\cos(\omega t + \psi + 2\tan^{-1}\omega/k)$

2. i. $(1/a)\log_e(ax + b) + const.$;
ii. $(ax/c) + \{(bc - ad/c^2\}\log_e(cx + d) + const.$;
iii. $\sec x + const.$;
iv. $-(1/a)\cot^{-1}(x/a) + const.$;
v. $\tan^{-1}\epsilon^x + const.$

3. i. $(x^3/9)(3\log_e x - 1) + const.$;
ii. $x(\log_e x)^2 - 2x\log_e x + 2x + const.$;
iii. $x\tan^{-1}x - \frac{1}{2}\log_e(1 + x^2) + const.$

5. i. 2 ; ii. 0 ; iii. π

Abstracts and References.

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PROPAGATION OF WAVES.

Variations in High Frequency Ground Wave Ranges.—A. H. Taylor. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 707-708.)

The results of experiments made by two naval ships on high frequency ground wave ranges indicate unexpected differences between day and night values, not predicted by present theory. The observations reported were taken on frequencies in the 12,000 and 16,000 kilocycle bands at distances between zero and 53 miles. The power of the transmitter was approximately 100 watts in the radio-frequency circuits, of which probably 60 per cent. went into the antenna. The daylight ground range in the 12,000 kilocycle band was found to be about 12 miles while the night range for the same frequency band was something over 50 miles. In the 16,000 kilocycle band the daylight ground wave range was not more than 3 miles, while the night range extended to 22 miles.

The author states that these results can only be interpreted by supposing some agency at work which produces a markedly greater absorption of the ground wave in the day-time than it does during the night hours; otherwise we should be forced to assume that we had to deal with some new kind of sky wave produced by a very low refracting or reflecting layer, which however is less likely owing to the absence of fading. Although these results are only in line with what we know of longer wavelengths, the differences between day and night ranges are then attributed to the different character of the sky waves in the two cases, while here we are dealing only with ground waves, the observations being taken well within the normal skip distance area.

A Suggestion of a Connection between Radio Fading and small Fluctuations in the Earth's Magnetic Field.—G. Breit. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 709-723.)

The fading of radio signals has been repeatedly referred to as an interference effect between ground and sky waves. Recently, however, it has become obvious that more than simple interference is involved. Thus short-wave transmission has shown that beyond a certain range signals are received entirely by an overhead route, and yet, in spite of this fact, the signals show fading. While this may be explained, at least partly, as a general shift in the height of the reflecting layer, experiments on the reflection of waves from the upper atmosphere have proved that fading exists for the reflected waves quite independently of interference with the ground wave. One suggestion as to the possible cause of the fading has supposed the downcoming ray to be a result of the interference of two or more rays, and some simple calculations are given here in order to show how the interference conditions between these two rays may change. The state of polarisation of a wave returned by the reflecting layer is studied as a function of (*a*) small changes in the intensity of the earth's magnetic field, (*b*) small changes in the frequency of the wave, and (*c*) small changes in the ionisation of the atmosphere.

It is shown that, for the special electron distribution considered, appreciable effects on the intensity of the signal are to be expected for fluctuations in the earth's field of the order of 5 gammas, for changes in the frequency of the order of 1,000 cycles, and for changes in the ionisation of the order of one part in 5,000. (The number applies to $\lambda =$ 70 metres.) The dependence of fading on range indicates that there is a certain range of maximum fading which is of the general order of 100 miles

Propagation of Short Waves.—(*Nature*, 24th September, 1927, p. 454.)

Using an antenna only 25 ft. long and a wavelength of 32.8 metres, an experimental radio station in America has been heard all over the world.

The General Electric Co. has obtained interesting results with waves of 5 metres: these waves were found to show a shadow effect very similar to that produced by light; also they were picked up 32 miles away when a power of only 60 watts was employed. The experiments are being continued.

Über die Temperatur in den höheren Schichten der Atmosphäre (On the temperature of the upper layers of the atmosphere).—H. Petersen. (*Physik. Zeitschr.*, 28, 14, pp. 510-513.)

Assuming that magnetic storms are due to corpuscular radiation from the sun (β rays) which are caught or deviated by the earth's magnetic lines of force, and attributing to the radiation properties similar to those ordinary rapid β rays possess, and assuming further that this radiation is wholly or partly absorbed at great altitudes, the author shows that such a quantity of heat is developed as to considerably raise the temperature of the absorbing masses of air, and that the conditions are such as to account for the rise of temperature with increasing height that Gutenberg calculated from observations on explosion waves (0°C. at 40 kilometres, 20° at 50 kilometres, and 40° at 60 kilometres).

Penetration of Radio Waves.—A. Eve, D. Keys and E. Denny. (*Nature*, 17th September, 1927, p. 406.)

In a letter to *Nature*, of 2nd July (these abstracts, *E.W. & W.E.*, September, 1927, p. 572), the desirability was expressed of obtaining information as to the extent to which radio waves can penetrate

the earth, and on 17th August, at the Caribou Mine, Colorado, the opportunity was offered of making satisfactory tests on this point. It was found that at a depth of 220 ft. below the surface, in a cross cut clear of wire, rails and pipes, KFEL Denver (248 metres) could be heard well from a loud-speaker, and then on proceeding to a depth of 550 ft., while carrier waves could be detected, no clear reception was possible in the morning, although in the evening KOA Denver (326 metres) was heard perfectly distinctly. In both cases the reception was by loop and maximum intensity was obtained when the loop pointed within a few degrees of Denver, about 50 miles away.

Previous experiments at the Montreal tunnel had shown that 40 metre waves were weak in penetrating power, that broadcasting waves were more effective, while longer waves of 10,000 metres surpassed both.

Results of Earth-Resistivity Surveys near Watheroo, Western Australia, and at Ebro, Spain.—W. Rooney and O. Gish. (*Terres. Mag. and Atmos. Elect.*, 32, 2, pp. 49-63.)

Description of an experimental investigation which shows that Watheroo, despite the presence of a surface layer of high resistivity sand, is a region of unusually high conductivity, comparable to a fresh-water area. The average value of the resistivity to depths of 100 metres is about 700 ohms per c.c., and to 600 metres a little over 5,000 ohms per c.c. The resistivity at Ebro, while lower at the surface, is considerably higher than that at Watheroo to depths of 300 metres or more, the average value being somewhat over 10,000 ohms per c.c. To depths of 100 to 300 metres, the current-density, as determined by combining resistivity results with records of potential gradient, differs very little at the two places.

ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY.

Atmospherics and the Atmosphere.—R. A. Watson Watt. (*Quart. Journ. Royal Meteorological Society*, 53, 222, pp. 169-172.)

Broadcast Talk No. 3, on "The Weather and its Ways," describing simply how atmospherics give information on the approach and direction of travel of a polar front and the weather consequently to be expected.

On Clicks and Grinders of Atmospherics.—H. Nagaoka. (*Proc. Imp. Acad., Japan*, 3, 2, 1927, pp. 64-67.)

The writer states that the clicks and grinders observed by radio-telegraphists appear to be similar electric disturbances in the upper atmosphere, but that while the former occur in the non-ionised region, the latter pass through the ionised layer. Accordingly clicks come in without much change of type, but grinders are greatly modified during the passage through the conducting medium and are accompanied by tails, tending to prolong the disturbance. A brief mathematical treatment based on Maxwell's equations for a slightly conducting medium is given elucidating this difference. The writer also states the possibility that grinders are caused by thunderstorms, the promiscuous waves generated by electric discharge passing through damp atmosphere, which is partially conducting, giving rise to the diffusive propagation found.

Thunderstorms.—G. C. Simpson. (*Quart. Journ. Royal Meteorological Society*, 53, 222, pp. 172-176.)

The fourth broadcast talk on weather topics, explaining in simple language the origin of the electricity in a thunderstorm as due to the breaking up of raindrops, when they become charged with positive electricity, the surrounding air receiving the corresponding negative charge, also describing the mechanism of a thunderstorm and the part played by ascending currents of air.

Remarkable Electrical Conditions accompanying West Texas Sand Storms.—E. George, W. Young and H. Hill. (*Physical Review*, September, 1927, p. 362.)

During West Texas sand storms the atmosphere is in a very unusual electrical condition. Severe shocks are sometimes received from radio antennæ, fence wires and automobiles. A radio antenna composed of stranded wire stretched at a height of about 73 ft. in an east and west direction between towers 282 ft. apart, formed the basis of preliminary measurements. Prevailing storms are from the west. Potentials of over 40,000 volts, as measured by spark gap between spherical electrodes, have been obtained and direct currents as high as 1.2×10^{-4} amperes measured.

Preliminary Notes on Electromotive Forces possibly produced by the Earth's Rotating Magnetic Field and an observed Diurnal-Variation of the Atmospheric Potential-Gradient.—G. Wait and H. Sverdrup. (*Terres. Mag. and Atmos. Elect.*, 32, 2, pp. 73-83.)

The current computed from the action of electromotive forces, due to the rotation of the earth's magnetic field, upon charged particles entering the upper atmosphere from the sun, shows a diurnal variation and annual variations of phase-angle and amplitude which are in remarkable agreement with corresponding variations of the atmospheric potential-gradient as actually determined from observations made at sea. Difficulty, however, is found in developing a physical basis to explain the relation between the two phenomena.

PROPERTIES OF CIRCUITS.

Modulation in Vacuum Tubes used as Amplifiers.—E. Peterson and H. Evans. (*Bell System Technical Journal*, 6, 3, 1927, pp. 442-460.)

Recent developments in amplifier design tending toward more rigorous quality requirements have shown that the solutions of Van der Bijl and Carson are inadequate for certain purposes since they are based upon a convenient assumption which is not satisfied in fact. In particular, a detailed investigation of carrier current repeaters

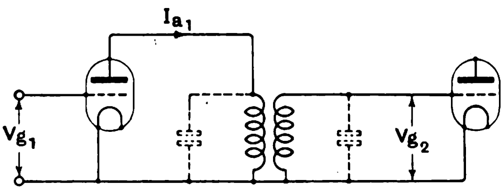
used for the simultaneous transmission of several channels, and upon which in consequence the modulation or cross-talk requirements are particularly severe, showed the modulation currents measured to be quite different from those specified by the theory, as was the law of variation of these currents with the circuit constants.

The cause of the discrepancy was found to reside in the neglect of the variation of the amplification factor (μ) with both plate and grid potentials. When the actual state of affairs was taken into account in the analysis by the application of a general method involving no assumptions, theory and experiment were found to be in good accord. The new expressions have been developed in terms of the amplification factor, the internal output resistance of the valve, and their differential parameters, which are involved in the representation of the characteristic valve equation by a double power series. Expressions for the current components are developed in terms of the coefficients of the series, and modifications of Miller's method for greater convenience and precision in determinations of valve characteristics are described from which the series coefficients may be evaluated.

Conclusions are drawn from the solutions as to desirable valve characteristics by which, for example, a single valve may take the place of two valves in push-pull connection. Finally, certain properties of different types of valve under conditions of maximum output power are compared on the basis of μ constant and μ variable.

DIE INDUKTIVE KOPPLUNG MIT PRIMÄRER UND SEKUNDÄRER ABSTIMMUNG IM ANSCHLUSS AN RADIORÖHREN. I. TEIL (Inductive coupling with primary and secondary tuning connecting valves).— H. Kafka. (*Zeitschr. f. Hochfrequenz.*, 30, 2, pp. 44-52.)

Investigation of the effect of inductive coupling with primary and secondary tuning for connecting two valves as shown below :—



The value and sharpness of tuning of the grid tension on the second valve produced by the coupling are of particular interest. It is shown that the inner resistance of the first valve has a very significant influence on the effect of the coupling. Inductive coupling with secondary tuning offers special advantages, since with loose coupling it enables the value and selectivity of the secondary grid current to be considerably increased. The influence of the degree of coupling on the value of the secondary grid current is represented by a locus diagram. For a certain degree of coupling the value of the secondary grid tension reaches an optimum value. Lastly, it is investigated to what extent the increase of selectivity obtainable with loose coupling can be utilised in practice. The experiments described are intended to be a starting point for the design of inductive couplings to connect valves in the case of high and intermediate frequency amplifiers.

AUDIO-FREQUENCY TRANSFORMERS.—J. M. Thomson. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 679-686.)

A method for calculating the amplification curve of an audio-frequency transformer is developed in terms of the usual constants of the transformer and valve. The distributed capacity of the coils and the mutual capacity between the primary and the secondary coils are represented by lumped capacities. The exciting current of the transformer is neglected. As the equation for the amplification in the vector form is rather involved an approximate formula is developed and its limitations pointed out.

ZUR THEORIE DES WIDERSTANDSVERSTÄRKERS (On the theory of the resistance amplifier). —H. Dänzer. (*Zeitschr. f. Hochfrequenz.*, 30, 1, pp. 26-28.)

Mathematical investigation of the influence of the battery tension, the high ohmic resistance in the anode circuit, and the grid-leak resistance on the amplification ratio. The ratio is found to be a maximum in general when the resistance in the anode circuit is equal to twice the grid-leak resistance. The dependence of the maximum amplification ratio upon the factors coming into question is discussed.

RESISTANCE AMPLIFIERS.—P. Tyers. (*Electrical Review*, 9th September, 1927, p. 416.)

Some of the statements in this article are discussed by Mr. F. Phillips in the *Review* of 23rd September, p. 501.

LABILITEIT VAN EEN UIT *n* TRIODEN BESTAANDE VERSTERKER MET INACHTNAME VAN DE INTERELECTRODEN-CAPACITEITEN (Instability of an amplifier consisting of *n* triodes, taking account of the inter-electrode capacities.— K. Posthumus. (*Tijds. Nederland. Radiogenootschap*, 3, 3/4, 1927, pp. 106-112.)

Mathematical consideration of the influence of grid-anode capacity coupling on amplifier stability, in some simple cases, neglecting grid currents, parasitic back-couplings, and curvature of the characteristic.

FREQUENCY DEMULTIPLICATION.—B. van der Pol and J. van der Mark. (*Nature*, 10th September, 1927, pp. 363-364.)

Account of the utilisation of the remarkable synchronising properties of relaxation-oscillations to effect frequency demultiplication, a demultiplication of frequency up to the ratio 1 : 1/200 having been obtained.

EENIGE OPMERKINGEN OVER RELAXATIETRILLINGEN (Some remarks on relaxation oscillations).— H. O. Roosenstein. (*Tijds. Nederland. Radiogenootschap*, 3, 3/4, 1927, pp. 90-93.)

A mathematical note referring to Dr. van der Pol's paper (these Abstracts, *E.W. & W.E.*, August,

1927, p. 506), showing that relaxation oscillations can occur in a system where inductance is entirely absent, and that the inductance of the leads has no influence on the manner of oscillation of a multivibrator.

ÜBER KIPPSCHWINGUNGEN IN GEKOPPELTEN SCHWINGUNGSKREISEN MIT VERÄNDERLICHER SELBSTINDUKTION (On " tilting " oscillations in coupled oscillatory circuits with variable inductance).—R. Mayer and F. Sammer. (*Telefunken-Zeitung*, 8, 45/46, pp. 73-76.)

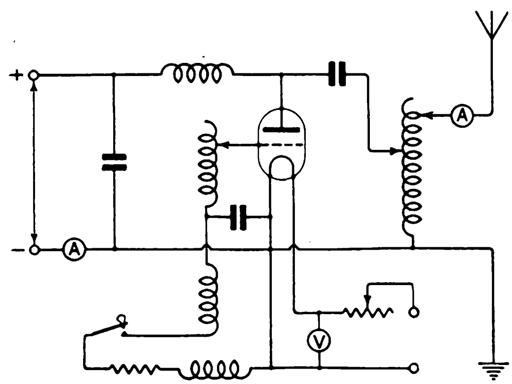
Account of the stationary current variations in coupled oscillatory circuits with an iron-containing inductance in the second circuit.

ON THE DESIGN OF AN INDUCTANCE COIL FOR AUDIO-FREQUENCIES HAVING AN IRON CORE WITH AN AIR GAP.—H. Nukiyama and K. Nagai. (*Tohoku Univ. Technol. Reports*, 6, 3, 1927, pp. 1-10.)

TRANSMISSION.

KORTE GOLFZENDERS IN HET ALGEMEEN EN DIE VOOR DE VERBINDING NEDERLAND-CURAÇAO IN HET BIJZONDER (Short wave transmitters in general and those for the service, the Netherlands-Curaçao in particular). — G. Schotel. (*Tijds. Nederland. Radiogenootschap*, 3, 5, April 1927, pp. 113-133.)

After explaining the need for a specially constructed transmitter for short waves, the author first discusses the circuit-arrangement in which the



antenna forms part of the anode circuit, as in the Huth-Kühn patent, and then goes on to consider the arrangement with indirect coupling. It is found, in the first case, that it is impossible, below a certain wavelength, to make the impedance of the valve circuit (including the capacity of the valve) sufficiently great for the triode to have good efficiency as a converter of direct into alternating current; and in the second case, that the loss due to the intermediate circuit detracts considerably from the total efficiency—by which is understood the ratio of the power radiated to that supplied to the anode. The author then describes his search for a system with good over-all efficiency: the circuit-arrangement developed is shown in the diagram.

Particulars with numerical values are given of the transmitters for communication between the Netherlands and Dutch West Indies, also a photograph of the Curaçao transmitter (wave range 20-80 metres).

ÜBER MODULATIONSLINIEN BEIM RÖHRENSENDER (On modulation lines in the case of valve transmitters).—W. S. Pforte. (*Zeitschr. f. Hochfrequenz.*, 30, 1, 1927, pp. 6-9.)

Modulation lines are curves representing the dependence of the antenna- or oscillatory circuit current upon the variation of individual circuit elements. These curves are plotted for the heating circuit, the grid circuit (grid tension, grid resistance, back coupling, back coupling capacity, back coupling parallel resistance), and the anode circuit (anode tension, anode resistance and oscillatory circuit resistance), mostly with two parameters: the back coupling and the tension applied to the grid.

FORMULAS FOR THE CALCULATION OF THE CAPACITY OF ANTENNAS.—F. Grover. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 733-736.)

A collection of formulæ covering different antenna types, together with tables of constants to aid in the calculations, and tables of the capacity itself for certain simple antenna systems, has been issued as a letter circular by the Bureau of Standards. This paper discusses the methods utilised and assumptions made in deriving the formulæ.

CALCULATIONS OF THE POLAR CURVES OF EXTENDED AERIAL SYSTEMS.—E. Green. (*E.W. & W.E.*, October, 1927, pp. 587-594.)

CALCUL DES CONSTANTES ELECTRIQUES ET MÉCANIQUES DES ANTENNES PSEUDO-SYMÉTRIQUES AVEC APPLICATION AUX ANTENNES GENRE FL (Calculation of the electrical and mechanical constants of pseudo-symmetrical antennæ, with application to antennæ of the FL type).—M. Stern. (*L'Onde Electrique*, 6, 67, July, 1927, pp. 304-321.)

The general method of treating problems of pseudo-symmetrical antennæ is recalled. Two concrete cases are studied for antennæ of the FL type, one with six wires and the other with ten, assuming certain practical data known. The validity of the hypotheses is discussed and the determination of electrical and mechanical constants by calculation is considered in detail.

ZIEHERSCHEINUNGEN BEIM LICHTBOGENSENDER (Oscillation hysteresis phenomena in the case of arc transmitters).—H. Winkler. (*Zeitschr. f. Hochfrequenz.*, 30, 1, 1927, pp. 1-5.)

The results are given of an investigation of the phenomena of oscillation hysteresis occurring in arc transmitters with close antenna coupling. The correctness of the explanation of the phenomena in accordance with Rogowski's theory of inductively coupled circuits was proved by quantitative experiments.

PROPAGATION OF PERIODIC CURRENTS OVER A SYSTEM OF PARALLEL WIRES.—J. Carson and R. Hoyt. (*Bell System Technical Journal*, 6, 3, 1927, pp. 495-545.)

Mathematical discussion, some results of which are applicable to wave antenna problems.

RECEPTION.

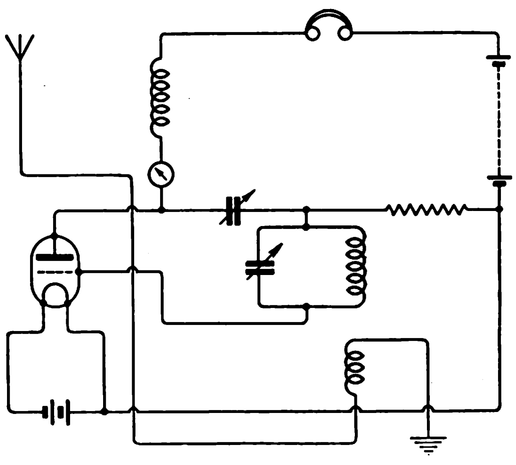
SUR LES APPLICATIONS D'UN TYPE PARTICULIER D'AMPLIFICATEUR À RÉACTION (On the applications of a particular type of amplifier with reaction).—P. Lejay. (*Comptes Rendus*, 185, pp. 500-502, 29th August, 1927.)

Account of the employment of very simple apparatus, comprising only a fixed and a variable resistance besides the valves, for detecting, eliminating atmospherics, amplifying, or as an oscillator.

THE AMPLIFICATION OF SMALL CURRENTS BY MEANS OF THE THERMO-RELAY AND THE PHOTO-ELECTRIC CELL.—J. Taylor. (*E.W. & W.E.*, October, 1927, pp. 627-633.)

NOUVEAU MONTAGE DE TRIODE DÉTECTRICE À REACTION (New circuit-arrangement for a detecting valve with reaction).—M. Caillat. (*L'Onde Electrique*, 6, 67, July, 1927, pp. 322-324.)

The circuit is here shown diagrammatically :—



For frame reception with very short waves, there is a further diagram showing the frame consisting of a single turn constituting the inductance of the oscillatory circuit.

VALVES AND THERMIONICS.

THE CHARACTERISTICS OF THERMIONIC RECTIFIERS. —C. L. Fortescue. (*Proc. Phys. Soc.*, 39, 4, 1927, pp. 313-317.)

In a paper published in 1919 (*Proc. Phys. Soc.*, 31, 5, 319) methods were given for calculating the behaviour of thermionic rectifiers working at high voltages and employing filaments with sharply defined saturation values for the emission current. The present paper extends the results there obtained to the case of rectifying valves working at low voltages with unsaturated electron currents, and briefly discusses the most economic conditions.

THE SHIELDED PLATE VALVE AS A HIGH-FREQUENCY AMPLIFIER.—R. T. Beatty. (*E.W. & W.E.*, October, 1927, pp. 619-625.)

THE NEW SCREENED VALVE.—N. W. McLachlan. (*Wireless World*, 31st August and 7th September, pp. 260 and 307, respectively.)

Discussion of the advantages and performance of the new screened valve with circuit calculations for tuned anode coupling.

SENDE-UND GLEICHRICHTER-RÖHREN MIT WASSER-GEKÜHLTER ANODE (Transmitting and rectifying valves with water-cooled anode).—G. Jobst and S. Ganswindt. (*Telefunken-Zeitung*, 8, 45/46, pp. 64-73.)

Various data of water-cooled valves are given and compared with those of valves cooled by radiation. The article is well illustrated.

SILICA VALVES IN WIRELESS TELEGRAPHY.—H. Morris-Airey, G. Shearing and H. Hughes. (*Journ. Inst. Elect. Eng.*, August, 1927, pp. 786-790.)

A Paper read before the Wireless Section, 4th May, 1927, an abstract of which appeared in *E.W. & W.E.* for June.

COOLED-ANODE VALVES, AND LIVES OF TRANSMITTING VALVES.—W. S. Picken. (*Journ. Inst. Elect. Eng.*, August, 1927, pp. 791-812.)

A Paper read before the Wireless Section, 4th May, 1927, an abstract of which appeared in *E.W. & W.E.* for June.

THE HOLWECK DEMOUNTABLE TYPE VALVE.—C. F. Elwell. (*Journ. Inst. Elect. Eng.*, August, 1927, pp. 784-785.)

A Paper read before the Wireless Section, 4th May, 1927, an abstract of which appeared in *E.W. & W.E.* for June.

AMERICAN RADIO VALVE DEVELOPMENTS.—F. H. Engel. (*Electrical Review*, 9th September, 1927, p. 443.)

Abstract of Paper presented at the recent National Electrical Manufacturers' Convention, U.S.A.

Details are given of some new "Radiotrons," which are believed to meet the latest demands of receiving-set design.

SURFACE LAYERS ON TUNGSTEN PRODUCED BY ACTIVE NITROGEN.—C. Kenty and L. Turner. (*Nature*, 3rd September, 1927, p. 332.)

Preliminary account of experiments from which some of the conclusions drawn are as follows: A clean tungsten surface at a dull-red heat, if placed in an atmosphere of nitrogen, activated either by a condensed discharge or by an electron bombardment at more than 22 volts, becomes covered with a nitrogen layer of the order of one atom deep. The effect of this layer, at this comparatively low temperature is to cool the surface. At relatively high temperatures, the same layer is probably

so unstable that only a small fraction of the surface can be covered at any one time, but it acts to increase the work function.

Über den Formierungsprozess in Oxydkathodenröhren (On the process of activation in valves with oxide cathodes).—F. Detels. (*Zeitschr. f. Hochfrequenz.*, 30, 1 & 2, 1927, pp. 10-14 and 52-59.)

A Paper divided into the following eight sections:

1. Previous work on the problem.
2. The process of activation.
3. Proof of the decomposition of the oxide.
4. Determination of the temperature of the incandescent filament.
5. Determination of A and Φ.
6. Conclusions drawn.
7. Mathematical calculations of temperature distribution.
8. Summary.

The experiments show that the gas escaping during the process of activation is oxygen, liberated through electrolytic decomposition of the oxide on the filament, and that it is the metal set free that is the emitting substance, and not the oxide. After determining the temperature of the filament by two different methods: that of raising the resistance and that assuming Maxwell's distribution of electronic velocity, the variation of the work of emission Φ and emitting capacity A was found from the Davisson saturation current formula as a function of the duration of the activation.

Both qualities were shown to decrease, Φ slowly and A very rapidly. Increasing the saturation current therefore centres on decreasing the work of emission. Attempts to increase the emitting capacity by nickelling and coppering the filament wire had the effect surmised, but not to the extent expected.

The Rates of Evaporation and the Vapour Pressures of Tungsten, Molybdenum, Platinum, Nickel, Iron, Copper and Silver.—H. Jones, I. Langmuir and G. Mackay. (*Physical Review*, 30, 2, August, 1927, pp. 201-214.)

Over de Diffusie van Thorium door Wolfram (On the diffusion of thorium through wolfram).—P. Clausing. (*Physica*, 7, 6, 1927, pp. 193-198.)

Evidence is given for the conclusion that the diffusion of *Th* does not occur through the *W*-lattice, but along the boundaries of the *W*-crystals; and the *Th*-layer on the outside of the *W*-wire is believed to be formed by a surface-mobility of the *Th*-atoms.

DIRECTIONAL WIRELESS.

Rahmen- und Goniometerpeilanordnungen (Frame and goniometer arrangements for obtaining bearings).—A. Esau. (*Zeitschrift f. Hochfrequenz.*, 29, 6, pp. 181-190, and 30, 1, pp. 15-23, 1927.)

A paper in three sections calculating the directional errors for the most different antenna forms in relation to polarisation and angle of incidence and showing how to obtain an arrangement that is free from directional error under all circumstances.

The first section deals with the three rotatable antenna arrangements: the frame, double antenna, and V antenna; the results being summarised as follows: The frame gives bearings without error only when the waves are incident horizontally, or with inclined waves when the polarisation is normal. If the plane of polarisation has become rotated, errors come into the observation whose values depend both on the inclination and polarisation of the wave. The double antenna arrangement yields correct bearings under all circumstances, provided that the ratio $\frac{\text{distance apart}}{\text{wavelength}} < 1$. The same is true for the rotatable V-antenna. Up to now only the first arrangement has found practical application.

The second section considers the goniometer consisting of two crossed frames. It is found that error is absent only when either the polarisation is normal or the incidence horizontal. Waves that are inclined and at the same time not polarised normally give rise to errors the magnitude of which increases with increasing angle of inclination, reaching a maximum for the angle of 90 degrees. The error attains its greatest value irrespective of the angle of inclination when the horizontal angle of incidence falls within one of the two frame planes; it disappears when this angle equals 45 degrees. With the angle of inclination kept constant, the error increases with the size of the angle by which the plane of polarisation deviates from the normal. If the two frame antennæ do not cross exactly at an angle of 90 degrees, an error is introduced even with horizontal wave incidence, the value of which increases with the divergence. Much the same is true when the two field coils of the goniometer are not exactly perpendicular to one another. While in the former case the instrument only reads correctly for an angle of incidence 90 degrees, in the latter case the same is true for an angle of 0 degree; also the error in the two cases is in opposite directions. If the two causes act together, the resultant error is somewhat less than that due to either separately, also the direction of the error changes sign between the angles of incidence 0 and 90 degrees. If the frames are not exactly equal, an error is introduced, even with horizontal wave incidence, whose value increases with the degree of their inequality. Error is a maximum with an angle of incidence of 45 degrees.

The third section shows that the only arrangement free from directional error, whatever the polarisation and angle of incidence, is one consisting of two pairs of non-directional antennæ at right angles to one another, provided the ratio d/λ is made as small as possible, any way, less than $\frac{1}{10}$ (d is the distance apart of the antennæ). If this condition is not fulfilled then errors occur even with horizontal wave incidence as is not the case with frames. The errors are greatest for the angles of incidence 22.5 or 67.5 and decrease in size as the angle of inclination becomes larger and the ratio d/λ smaller. When the pairs of antennæ and the field coils are not exactly perpendicular to one

another, error is introduced in just the same way as with frame goniometers.

The results calculated here show the same differences for the antenna forms as were found by Buchwald and Baldus in their observations of bearings finding on aircraft. (*Jahrb. d. drahtl. Telegraphie u. Telephonie*, 15, 1920, p. 214.)

Über das Peilen von Drehfeldern mit Rahmen und Hilfsantenna (Taking bearings on rotating fields with frame and auxiliary antenna).—F. A. Fischer. (*Zeitschr. f. Hochfrequenz.*, 30, 1, pp. 23-25.)

According to recent views on the propagation of wireless waves, directional errors are not caused through the ray travelling along the earth's surface being deviated from its original direction but through one or more space rays arriving simultaneously at the receiver, with any phase, direction and polarisation (Smith-Rose and Barfield, *J.I.E.E.*, 64, 1926, 831), and which are more or less reflected according to the wavelength and the electric constants of the ground (conductivity, dielectric constant and permeability).

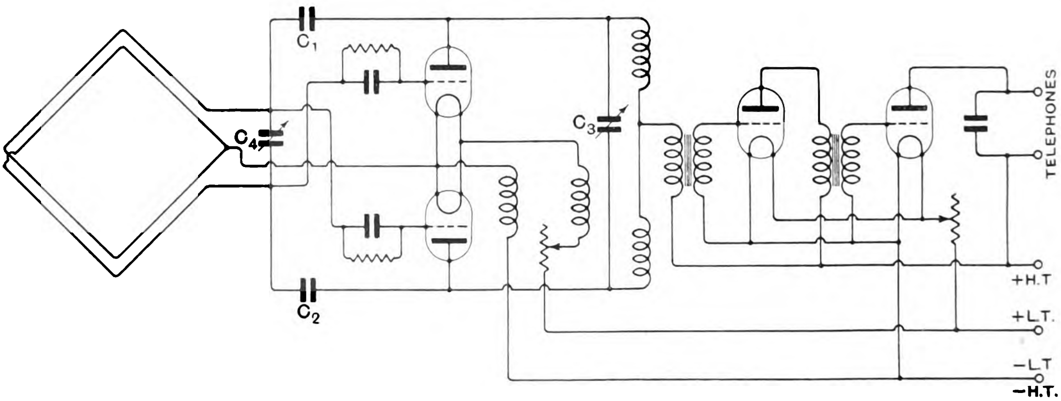
Now Heilitag has thoroughly investigated the directivity of an ideal frame antenna influenced simultaneously by two radio waves of the same frequency, but differing in direction, intensity and phase (*Jahrb. d. drahtl. T. u. T.*, 21, 1923, p. 77) and he arrived at the result that no conclusion can be drawn as to the magnitude of the directional error and the reliability of the observations from the quality of the minimum, as is shown again here. In general the direction of the long axis of the ellipse is indicated with a blurred minimum. Heilitag assumed an ideal frame, but in practice it is impossible to construct a frame direction finder so symmetrically that there is no small "antenna effect." This introduces a disturbing E.M.F., in addition to the frame E.M.F., and 90 degrees out of phase with it. To compensate for this, Telefunken employs the "auxiliary antenna," a small vertical wire antenna, which must be sufficiently mistuned to the arriving wave, since it has to induce an E.M.F. 90 degrees out of phase with it in the frame circuit. The auxiliary circuit is so coupled to the frame circuit that it produces in it an E.M.F. which just wipes out the E.M.F. of the antenna effect, thereby making the blurred minimum an absolute one.

It is investigated mathematically here how the combination of frame and auxiliary antenna takes bearings on a rotating field. The calculation is first made assuming the earth to be a perfect reflector, and then for the general case. It is found that the frame direction finder with auxiliary antenna, when taking bearings on elliptical rotating fields produced through several rays meeting at the receiver, always gives an absolute minimum, whose direction does not coincide with that of the long axis of the rotating field.

While the ideal frame always gives the direction of the long axis of the ellipse, even when the rotating fields are due to the presence of a back radiated field (as from the masts of a ship), with the frame direction finder and auxiliary antenna in this case, it depends on the coupling between the auxiliary antenna and the back radiation field. In practice, the auxiliary antenna is usually so placed that this coupling is absent, and then the antenna compensates the component of the back radiation field that is 90 degrees out of phase with the incident wave.

Über Rahmenpeilen mit kurzen Wellen (Taking bearings with a frame on short waves).—F. Michelssen. (*Telefunken-Zeitung*, 8, 44, pp. 66-71.)

A frame receiver for position-finding is described for the wave-range 18-120 metres, and the difficulties in developing it are pointed out. A circuit diagram is shown below.



Experimental investigation over land showed that sharp minima could be obtained only for short distances. Over sea, reliable bearings by day and night could not be guaranteed for more than 10 sea miles from the transmitter—and that with wooden ships. For iron ships, the errors with short waves are so exceptionally large and depend so markedly upon the frequency that their compensation is too difficult. It is concluded that the use of short waves for direction-finding is not practicable

and that the proved range of 600-1,100 metres must be retained at least for the present.

Über die Peilbarkeit kurzer Wellen auf See bei Tag und Nacht (On the possibility of taking bearings on short waves at sea, by day and night).—F. Michelssen. (*Telefunken-Zeitung*, 8, 45/46, pp. 96-99.)

Further details are given of the experiments described in the previous number of this periodical, which led to the conclusion that the employment of short waves for taking bearings is not practicable. It is stated that the best service a frame direction finder with auxiliary antenna can render at sea is in the investigation of propagation phenomena (for determining the distances to which the surface wave, with the small absorption over sea-water, affects the receiver simultaneously with a space wave, and then perhaps at what distance, and time of day, silent zones occur over sea for the various wavelengths.

Die Ermittelung wahrer Funkstrahlrichtungen auf Landpeilstationen (Finding the true direction of a radio ray with a land direction-finder).—D. Nitzsche. (*Telefunken-Zeitung*, 8, 44, pp. 72-78.)

When direction-finding on land, the incoming wave is frequently deviated by conducting structures in the neighbourhood of the receiver, as always happens on board ship. In order to determine what corrections have to be made for these systematic errors, the simplest way is to take observations on known stations, and compare the results obtained with the true directions. The true directions have therefore to be found. This paper discusses the construction and use of the various charts and finds that a gnomonic projection is best for direction-finding, as on it great circles are drawn as straight lines and a great circle is the shortest distance between two points on a sphere and consequently the path taken by radio waves. The fact that the projection is not angle true only comes in for distances that are at present too great for reliable direction-finding. In the absence of a suitable chart, the direction has to be calculated, which is explained with the help of an example. Thus with the correction to be applied to the reading observed in every direction known, the receiver is in a position to find the true direction of any unknown transmitting station.

Weiterer Ausbau der Funkbeschickungstheorie (Further development of the quadrantal error theory).—F. A. Fischer. (*Telefunken-Zeitung*, 8, 44, pp. 63-66.)

The general equation for quadrantal errors is given (*cf. T.-Z.* No. 42). It is found that while a ship's listing mostly reduces quadrantal error, its inclination lengthwise increases it. An important result of the investigation for frame compensation theory is that a frame compensates independently of the frequency when it has the same natural oscillation and the same damping as the ship (*cf. Annalen der Hydrographie*, 1926, xi, or *E.T.Z.*, 1926, 50).

Beitrag zur Kompensierung des Antenneneffektes von Peilern (Contribution to the compensation of the antenna effect in direction-finders).—F. Michelssen. (*Telefunken-Zeitung*, 8, 44, pp. 71-72.)

In order to obtain a sharp minimum, the E.M.F. produced by the electric vector due to unavoidable dissymmetry in the receiver relatively to earth must be compensated. Two methods for achieving this are explained here: coupling to the frame circuit (1) an aperiodic antenna, or (2) a tuned auxiliary frame.

Ein gegenazimutaler Kartenentwurf zur Ermittlung der Azimutgleichen für kleine und mittlere Entfernungen von der Funkbake (Construction of an azimuthal chart for determining lines of the same azimuth for small and medium distances from the transmitter).—W. Immler. (*Zeitschr. f. Hochfrequenz.*, 30, 2, pp. 60-66.)

Electromagnetische Stralenbundels (Electromagnetic beams).—R. Mesny. (*Tijds. Nederland. Radiogenootschap*, 3, 3/4, 1927, pp. 49-66.)

Discussion of the properties of curtain antennæ for producing beams. The advantages of employing a single wire bent in the shape of the Greek key-pattern are described, the polar curves obtained being compared with those produced by other methods. With regard to rotating beacons, a unidirectional system consisting of two groups of two antennæ is stated to be the simplest way of obtaining the sharpest beam (see *L'Onde Electrique* for last May, pp. 181-199, these Abstracts *E.W. & W.E.*, August, 1927, p. 508).

MEASUREMENTS AND STANDARDS.

Distortion of Resonance Curves of Electrically-Driven Tuning Forks.—E. Mallett. (*Proc. Phys. Soc.*, 39, 4, 1927, pp. 334-358.)

The dissymmetry may be of two different types: firstly, that of a device acting as a single system which with larger forces and consequently larger amplitudes gives a distorted resonance curve due to the non-linearity with amplitude of the forces brought into play, and secondly a "coupled circuit" effect occurring at small amplitudes as well as large ones. The conclusion is drawn that for any purpose where it is important that the frequency of the fork should be as absolutely constant as possible, it is necessary to work with very small amplitudes of vibration.

Notes on the Testing of Audio-Frequency Amplifiers.—E. T. Dickey. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 687-706.)

The more necessary of the various points which must be tested in examining the performance of audio-frequency amplifiers are outlined, and a method of test procedure, found by the author to have desirable characteristics from the points of view of accuracy, speech, and simplicity of operation, is described. The method permits the complete curve of amplification *v.* frequency for the

amplifier under test, to be drawn directly by the test equipment in a very short time. A type of valve voltmeter found convenient for measurement of amplifier output potential is described. Amplifier wave form distortion and overloading are discussed, and methods for testing them recommended.

EINE NEUE METHODE ZUR MESSUNG DES DÄMPFUNGSWIDERSTANDES VON SCHWINGUNGSKREISEN (A new method of measuring the damping resistance of oscillatory circuits).—L. Stürmer. (*Zeitschr. f. Hochfrequenz.*, 29, 6, pp. 192-194.)

Description of a method applicable to antenna and oscillatory circuit resistances greater than 3-8 ohms in the case of short waves (300-1,000 metres) and greater than 3-5 ohms with long waves (above 1,000 metres). The average accuracy is 1-5 per cent. according to the value of the resistance sought. The result is practically independent of the coupling with the auxiliary circuit, and the method requires very little energy for the measurement, and is adaptable to any valve wavemeter with self-excitation.

STANDARD FREQUENCY DISSEMINATION.—M. S. Strock. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 727-731.)

A paper dealing with standard frequency dissemination through the medium of radio transmission, for which the Bureau of Standards has three avenues: standard frequency transmissions; selection by actual frequency measurements of certain transmitting stations which are termed "standard frequency stations"; and the selection of certain "constant frequency stations" which maintain their frequencies close to the licensed values.

LA MESURE EXACTE ET PRÉCISE DES LONGUERS D'ONDE DANS LES STATIONS D'EMISSION (Precise measurement of the wavelengths of transmitting stations).—R. Braillard and E. Divoire. (*L'Onde Electrique*, August, 1927, pp. 357-387.)

Detailed study of an accurate wavemeter, including the value of the inductance and capacity, the indicating circuit and the method of calibration.

HET METEN VAN CAPACITEITEN EN HET AANTOONEN VAN CAPACITEITSVERANDERINGEN (The measurement of capacities and indication of change of capacity).—J. W. Alexander. (*Physica*, 7, 6, 1927, pp. 213-221.)

The method of measurement is a substitution method: first, the total capacity is found of a variable precision condenser connected in series with a condenser of known capacity, the unknown capacity is then connected in parallel with the known condenser and the total capacity again measured, and from the alteration of the precision condenser required to give the previous total capacity the unknown capacity is determined. The capacity is made to form part of an oscillating circuit and the turning point of the resonance curve employed to indicate adjustment. Comparisons with Whiddington's method (*Phil. Mag.*, 40, 634, 1920), which has the same object in view, shows the method to be not more sensitive than his. The effect of error in the readings is calculated.

MEASUREMENT OF INDUCTANCE BY THE SHIELDED OWEN BRIDGE.—J. Ferguson. (*Bell System Technical Journal*, 6, 3, pp. 375-386.)

The investigation shows that the Owen Bridge is well adapted to the accurate measurement of inductance and effective resistance to above 3,000 cycles. The construction of a shielded bridge for audio frequencies is described and a theoretical discussion given.

NOTE ON PIEZO-ELECTRIC GENERATORS WITH SMALL BACK ACTION.—A. Hund. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 725-726.)

Brief discussion of three circuit arrangements.

EINE PRAKTISCHE FASSUNG FÜR PIEZO-QUARTZ-PLATTEN (A practical mounting for piezo-quartz plates.—V. Gabel. (*Zeitschr. f. Hochfrequenz.*, 29, 6, pp. 194-195.)

Unfortunately the frequency of a quartz plate depends upon the width of the air-gap between the quartz surface and the electrodes and, as found by Dr. Dye, the smaller the air-gap, the more pronounced the effect; also the plate being situated asymmetrically between the electrodes exerts a certain influence. The author consequently made attempts to do away with the air-gap altogether by coating over the two surfaces of the quartz with a thin layer of metal. He describes the process of first chemically silvering the plate and then coppering it electrolytically. Plates thus treated can be very simply mounted in a case of any insulating material.

A WIRELESS WORKS LABORATORY.—P. K. Turner. (*Journ. Inst. Elect. Engineers*, September, 1927, pp. 881-902.)

Paper read before the Wireless Section, 18th May, 1927, pp. 881-902, an abstract of which appeared in the July number of *E.W. & W.E.*, pp. 422-429.

SUBSIDIARY APPARATUS AND MATERIALS.

H.T. FILTER CIRCUITS FOR D.C. MAINS.—J. Owen Harries. (*E.W. & W.E.*, October, 1927, pp. 613-618.)

A NEW FREQUENCY TRANSFORMER OR FREQUENCY CHANGER.—I. Koga. (*Proc. Inst. Radio Engineers*, 15, 8, pp. 669-678.)

Explanation of the employment of a triode oscillator to obtain alternating current having a frequency which is any fractional value of the frequency of a supplied current. The phenomenon seems to be due to the "attraction" of two nearly equal frequencies occurring in the triode circuit and to the non-linear characteristic of a triode.

RADIO-FREQUENCY TRANSFORMERS: THEIR APPLICATION TO SCREENED VALVES.—N. W. McLachlan. (*E.W. & W.E.*, October, 1927, pp. 597-600.)

THE PROPERTIES OF THE CIRCLE DIAGRAM FOR TELEPHONIC FREQUENCY INTERVALVE TRANSFORMERS.—F. E. Hackett. (*E.W. & W.E.*, October, 1927, pp. 601-604.)

DIE FREQUENZSTEIGERUNG VERMITTELS STARK GESÄTTIGTER TRANSFORMATOREN (Frequency raising by means of highly saturated transformers).—M. Osnos. (*Telefunken-Zeitung*, 8, 45/46, pp. 76-82.)

LOUD-SPEAKER DIAPHRAGMS.—N. W. McLachlan. (*Wireless World*, 21st September, 1927, pp. 357-361.)

The second article of a series, discussing the air pressure and energy distribution in the space surrounding the diaphragm.

THE KONE LOUD-SPEAKER.—S. Hill. (*Electrical Communication*, 6, 1, 1927, pp. 24-28.)

SOME MEASUREMENTS OF A "STALLOY" CORE WITH SIMULTANEOUS D.C. AND A.C. EXCITATION.—L. B. Turner. (*E.W. & W.E.*, October, 1927, pp. 594-596.)

STATIONS: DESIGN AND OPERATION.

THE SAINT-HUBERT AERODROME WIRELESS STATION.—(*Wireless World*, 28th September, 1927, pp. 447-448.)

Description of the station, recently opened by the Belgian Department of Aeronautics, which has been constructed to deal with the traffic of two important international air routes, viz., Amsterdam-Brussels-Basle and Paris-Cologne-Berlin.

BROADCASTING IN INDIA.—V. A. M. Bulow. (*Wireless World*, 7th September, 1927, pp. 311-314.)

A description of the Bombay station.

WAVELENGTH AND POWER OF EUROPEAN STATIONS. —(*Wireless World*, 28th September, 1927, pp. 149-454.)

A list, as complete as possible, of European broadcasting stations in order of wavelength, with a map giving the geographical position of each station.

GENERAL PHYSICAL ARTICLES.

THE CALIBRATION AND PERFORMANCE OF THE RAYLEIGH DISC.—E. Barnes and W. West. (*Journ. Inst. Elect. Engineers*, September, 1927, pp. 871-880.)

Owing to recent developments in telephony, the use of the Rayleigh disc for acoustic measurements has become increasingly important. The first part of the paper deals in general with methods of calibration of a Rayleigh disc as an instrument for measuring small air-particle velocities, and describes the method that has been adopted for calibration. The second part is concerned with comparative tests between discs of different sizes and composition at audio frequencies, and with the effects of internal resonance of mica discs. The third part summarises the general considerations affecting acoustic measurements and the errors liable under different conditions of use.

SUR UNE MÉTHODE D'OBSERVATION DE VARIATION DE CONSTANTES DIÉLECTRIQUES (On a method of observing variation of dielectric constants).—G. Guében. (*L'Onde Electrique*, August, 1927, pp. 388-392.)

During the course of a series of investigations on the effect of radioactive radiation on dielectrics, the author was led to seek whether this radiation, which produces an alteration of the conductivity of the dielectric, has also an action on its dielectric constant. To this end a method was studied capable of detecting small variations of capacity resulting from a variation of the dielectric constant. The best method under the given conditions was found to be a modification of that described by E. Meyer in the *Wireless World*, No. 381, p. 805, 1926. The method is explained in detail: its sensitivity is such as to detect a variation of dielectric constant equal to at least .001 of its value. At present the method is being employed to investigate a variation of dielectric constant of a whole series of dielectrics under the action of radium rays. Up to now the tests carried out have yielded negative results.

CHANGEMENTS DES PROPRIÉTÉS OPTIQUES DU QUARTZ SOUS L'INFLUENCE DU CHAMP ELECTRIQUE (Changes in the optical properties of quartz under the influence of an electric field).—M. Ny Tsi Ze. (*Comptes Rendus*, 185, pp. 195-197.)

It is found that charging positively the extremity of the electric axis, that would become positive by a compression exerted in the direction of the axis, increases the double refrangibility in this direction and diminishes it in the direction normal to the optical and electrical axes. The phenomena change in sign when the electric field is reversed and their magnitudes are proportional to the fields.

QUELQUES OBSERVATIONS FAITES SUR LE QUARTZ PIÉZO-ÉLECTRIQUE EN RÉSONANCE (Some observations on resonant piezo-electric quartz).—E. P. Tawil. (*Comptes Rendus*, 185, pp. 114-116, 11th July, 1927.)

In a paper last year (*C.R.* 183, p. 1,099) the author described variations in the optical properties of quartz when it vibrates piezo-electrically. The present paper gives a detailed account of further phenomena.

THE TEMPERATURE VARIATION OF THE ELASTICITY OF ROCHELLE SALT.—R. Morgan Davies. (*Nature*, 3rd September, 1927, p. 332.)

Valasek (*Phys. Rev.*, 478, 1922) has studied the temperature variation of the piezo-electric modulus of Rochelle salt. He found abrupt change in the values of this modulus at temperatures of $-15°$C. and $23°$ C., using crystal slabs with their length at $45°$ with the b and c crystallographic axes. The object of this note is to point out that there

is evidence for the existence of similar discontinuities in the values of the elastic constants of this crystal at these two temperatures.

A Theory of the Gravitational Field in the Light of Maxwell's Theory.—C. Venkata Row. (*Physical Review*, 30, 2, August, 1927, pp. 189-200.)

The theory starts from the fact that gravitational forces obey the inverse square law in common with electric and magnetic forces; from this it is inferred that Newton's law of gravitation must be developed into a theory of field-action on much the same lines as Coulomb's law has followed; as a first step towards this, the two principles, namely, Hamilton's principle and the special principle of relativity, on which Maxwell's theory is founded, are shown to be sufficient to determine uniquely Lorentz's law of electromagnetic force. Inertia and gravitation are recognised as only different aspects of the same phenomenon. Newton's inertial frame is shown to mark a fundamental physical medium in which matter is embedded, the medium being modified near large masses such as the sun.

Sur les Equations de l'Electromagnetisme (On the equations of electromagnetism).—F. Gonseth and G. Juvet. (*Comptes Rendus*, 185, pp. 341-343.)

A mathematical note with the object of formulating a five-dimensional relativity whose equations supply the laws of the gravitational and electromagnetic fields and the movement of a charged material point also the equation of M. Schrödinger's waves.

Les Equations de l'Electromagnetisme et l'Equation de M. Schrodinger dans l'Univers à Cinq Dimensions (The equations of electromagnetism and M. Schrodinger's equation in the five-dimensional universe).—F. Gonseth and G. Juret. (*Comptes Rendus*, 185, pp. 535-538.)

Light-Quanta and Maxwell's Equations.—N. Rashevsky. (*Phil. Mag.*, 4, 22, September, 1927, pp. 459-465.)

In a recent paper (*Phil. Mag.*, 1926, p. 1,208), Prof. Kasterin attempted to show that, in spite of the generally accepted opinion, the conception of light corpuscles is compatible with Maxwell's equations and that the form of the light-quantum theory, proposed by Sir J. J. Thomson, may be obtained as a particular solution of Maxwell's equations, provided we also consider discontinuous solutions of these equations. The writer here discusses the difficulties involved with a view to elucidating the fundamental question.

Sur la Métrique de l'Espace à 5 Dimensions de l'Electromagnetisme et de la Gravitation (On the metric of the five-dimensional space of electromagnetism and gravitation).—F. Gonseth and G. Juvet. (*Comptes Rendus*, 185, pp. 412-413.)

D. E. H.

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPRECOJ DE CIRKVITOJ.

Kelkaj Mezuroj de "Stalloy" (Ŝtalaloja) kerno kun Samtempa Kontinukurenta kaj Alternkurenta Ekscitado.—L. B. Turner.

La artikolo priskribas mezuradojn de "Stalloy"—kerna bobeno, kun grandeco kiel malaltfrekvenca transformatoro, ŝokbobeno, k.t.p. La mezura metodo estas priskribita kaj la rezultoj estas prezentitaj en formo de tabelo kaj serio de kurvoj montrantaj induktancon kontraŭ K.K. miliamperoj por diversaj valoroj de alternanta voltkvanto po 90 cikloj ĉiusekunde. Oni faras rimarkigojn pri la rezultoj kiel helpoj je funkciado kaj desegnado.

La Proprecoj de la Cirkla Diagramo por Telefonaj Frekvencaj Transformatoroj Intervalvaj.—Prof. F. E. Hackett.

La artikolo traktas pri la cirkla diagramo por konsiderado pri la malaltfrekvenca intervalva transformatoro, kiel evoluigita de D-ro. Dyer (en *E.W. & W.E.*, Sep., Okt., & Nov. 1924a). Aparte, ĝi donas alian metodon por kalkulado, kiu estas iom pli simpla, tial, ke ĝi evitas la pezaĉajn esprimojn ordinare uzitajn kiam oni traktas pri paralelaj cirkvitoj. La ekvivalenta cirkvito de la transformatoro estas diskutita kaj esprimo ricevita por la kalkulado de la cirkla diagramo, kies evoluigo estas poste diskutita.

Estas ankaŭ noto pri la utiligo de vektoraj diagramoj rilate al ĉi tiuj kalkuladoj.

RICEVADO.

Altatensiaj Filtrilaj Cirkvitoj por K.K. Elektraj Ĉeftuboj.—J. H. Owen Harries.

La aŭtoro unue diskutas la temon pri ondetado je ĉeftuba provizado, kaj tiam iras al konsiderado pri filtrilaj cirkvitoj. Sekcio traktas pri la determino de praktikaj valoroj de cirkvitaj konstantoj, kaj diagramo estas donita de la fina cirkvito de l'aŭtoro.

Oni ricevas esprimon por la proporcio de elmeta kontraŭ enmeta ondeta voltkvanto kaj por hazardaj kurentoj (aparte ĉe elektraj sistemoj kie la pozitiva ĉeftubo estas terigita). Fina noto traktas la utiligon de filtriloj por kaj Altatensia kaj Malaltatensia provizado.

RADIO-FREKVENCAJ TRANSFORMATOROJ: ILIA APLIKADO AL ŜIRMITAJ VALVOJ.—D-ro. N. W. McLachlan.

La aŭtoro unue konsideras la okazon de radiofrekvenca transformatoro (kun agordita sekundario) kiam uzita kune kun certaj fabrikoj de tri-elektrodaj valvoj difinitaj. La ekvivalenta cirkvito estas analizita kaj esprimo deduktita por pligrandigado. La rezonado estas tiam etendita al okazo de ŝirmita valvo ("Osram" Ŝirmita Valvo S625), kaj la pliboniĝo je amplifado montrita. La aplikado de la ŝirmita valvo al la okazo de la agordita valvo estas poste pritraktita, kaj la aŭtoro finas per sekcio pri la selektiveco de la transformatoro.

LA VALVO KUN ŜIRMITA PLATO KIEL ALTFREKVENCA AMPLIFIKATORO.—R. T. Beatty.

La aŭtoro unue diskutas la proprecojn de valvo kun plene ŝirmita anodo, donante kurvojn por la ŝirmita valvo de Hull. Li poste transiras al komercaj valvoj kun ŝirmitaj platoj, donante karakterizojn kaj detalojn de la inter-elektroda kapacito, kompare kun la okazo de la Valvo Hull'a. Oni priskribas eksperimentojn pri la voltkvanta pligrandigo de krado al plato, kun tabeligo de rezultoj. La aŭtoro tiam traktas pri la stabileco de unuŝtupa amplifikatoro kun agorditaj kradoj kaj agorditaj anodaj cirkvitoj, denove donante eksperimentajn rezultojn obtenitajn per la komerca tipo de ŝirmita valvo.

Fine li diskutas tutan voltkvantan amplifadon obteneblan, lasante tiajn demandojn, kiel selektiveco kaj multŝtupa amplifado, por traktado dum iu estonta okazo.

DIREKTA SENFADENO.

KALKULADO DE LA POLUSAJ KURVOJ DE ETENDITAJ ANTENAJ SISTEMOJ.—E. Green.

La artokolo traktas pri metodoj por kalkuli la proprecojn de direktaj antenoj, kiel ekzemple, la Marconi'a Radia Anteno.

Unue konsiderita estas la okazo de linio da antenoj, ĉiu apartigita per frakcio de ondolongo, kaj la tuto kelkajn ondolongojn longa. La determino de la vektoroj laŭ diversaj direktoj estas donita, polusaj kurvoj estante montritaj por sistemoj 2 λ larĝaj kaj 10 λ larĝaj. La efekto de reflektilo estas ankaŭ montrita. Poste diskutita estas la energio-pligrandiĝo de etendita antena sistemo, kompare kun unuobla anteno, kaj la energio-pligrandiĝo kaŭze de etendiĝo je la larĝeco de l'antena sistemo. Aliaj sistemoj de etenditaj antenoj estas ankaŭ konsideritaj, inkluzive unu por kuncentrigo de energio en la vertikala ebeno.

ĜENERALAJ FIZIKAJ ARTIKOLOJ.

LA AMPLIFADO DE MALGRANDAJ KURENTOJ PERE DE LA TERMO-RELAJO KAJ LA FOTO-ELEKTRA ĈELO.—J. Taylor.

La temo estas enkondukita per ĝenerala diskutado pri termo-elektraj voltkvantoj kaj termo-kuploj. Poste estas priskribita la termo-relajo (ŝuldita al Moll), konsistanta el strio de "Constantan Manganin-Constantan" enfermita en vakuigita bulbo. La lumo el spegula galvanometro, reflektita je la centron de la manganino, lasas la sistemon je termo-elektra ekvilibro, sed la defleksigo de la luma punkto detruas la ekvilibron kaj naskas termo-elektran elektromovan forton, kiun oni povas utiligi por funkciigi alian galvanometron, la aranĝo funkciante efektive kiel relajo.

Iom simila aplikado de la fota-elektra ĉelo estas ankaŭ priskribita.

DIVERSAĴOJ.

RESUMOJ KAJ ALUDOJ.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

MATEMATIKO POR SENFADENAJ KOMENCANTOJ.—F. M. Colebrook. Daŭrigita el antaŭaj numeroj.

La nuna parto traktas pri Vektoroj, Funkcioj kaj la diferencigo de Vektoroj; poste transiras al Integrala Kalkuluso, traktante pri Sendifina Integrado, Integrado de la Sumo aŭ Diferenco de Funkcioj, Integrado per Partoj Definita Integrado, la Meza Valoro de Funkcio, k.t.p.

Correspondence.

Letters of interest to experimenters are always welcome. In publishing such communications the Editors do not necessarily endorse any technical or general statements which they may contain.

The Theory of the Flat Projector.

To the Editor, E.W. & W.E.

SIR,—The article by Dr. J. A. Fleming on "The Theory of the Flat Projector," in the July issue of *E.W. & W.E.*, appears to be misleading in some places.

1. It is asserted that, "owing to the inductance of the reflector wire and its low resistance, the electric current, generated in it, lags nearly $\pi/2$ behind the inducing E.M.F. in phase."

This is not true because the reflector wire, being in length equal to half a wavelength, behaves as a pure resistance. Therefore the current in a reflector wire is in phase with its E.M.F., and as far as this E.M.F. is due to the current in the aerial wire just in front of it, it is $\pi/2$ out of phase with this last-mentioned current (and not π).

2. Further, it is asserted that "this inducing E.M.F. is $\pi/2$ in phase behind the current in the aerial wire." But this is not exact, the E.M.F. being $\pi/2$ in phase *before* the current in the aerial wire (it is understood that the same positive sense is chosen for both wires: aerial and reflector). This can be proved easily, supposing that the inductive field—which has a sinusoidal distribution in space —is stable, and that the reflector wire is moving with the velocity of light towards the aerial wire; then, applying Fleming's right-hand rule, the sense of the E.M.F. can be found (considering only the magnetic induction).

3. In calculating the field due to the current in the first reflector wire at a point P, it is stated that the field is proportional to:

$$\sin\left[m\left(\gamma+\frac{\lambda}{4}\cos\theta\right)-n\left(t-\frac{T}{4}\right)\right]$$

The last term in the brackets

$$n\left(t-\frac{T}{4}\right)$$

is justified by "taking in account the phase difference $T/4$ of the reflector wire current and the E.M.F. creating it."

This would be true—not considering, for the present, the above two points—if the E.M.F. phase is taken as phase origin (in time) for the field. But as it is stated in the article that this E.M.F. lags $\pi/2$ behind the aerial wire current (which creates the inductive field), one must consider a new phase difference $T/4$ in the field expression. Therefore the last term would have been

$$n\left(t-\frac{T}{2}\right)$$

But now considering also the above two points, the reflector wire current being in phase with the E.M.F., the first phase difference $T/4$ does not exist, and then the E.M.F. being $\pi/2$ in phase before the current in the aerial wire, the second difference of phase $T/4$ is of an opposite sign to that considered before.

Therefore the field due to the first reflector wire at a point P is proportional to

$$\sin\left[m\left(\gamma+\frac{\lambda}{4}\cos\theta\right)-n\left(t+\frac{T}{4}\right)\right]$$

when this field has the same phase origin as the field due to the first aerial wire current (in time).

4. Then, if the above points are taken into account we cannot more say that in order to obtain the resultant field we have to subtract algebraically H' from H, but we must add the two fields.

5. The manner in which the numerical example is treated is without interest, because, for different points P of a circle round the emission station, the calculated values of the fields are only instantaneous values for one and *the same moment*. All these values do not represent the maximum values of the fields at the corresponding points, and only a diagram, containing these maximum values plotted against the direction θ, is interesting.

6. In the numerical example given in this article, and also in some places of the general case, it is supposed that the aerial wires are spaced half a wavelength apart ($d=\lambda/2$). However, actually, in the Marconi Beam Stations, $d=\lambda/4$ or $d=3\lambda/4$ is always used. In these cases some of the conclusions to which the author arrives are no more exact and specially it can no more be easily asserted that the current in a reflector wire is due only to the current of the aerial wire in front of it.

London, N.W.1. TUDOR A. TANASESCU.

To the Editor, E.W. & W.E.

SIR,—I do not agree with the criticisms which Mr. Tanasescu makes on my article on the above in your July issue. Nothing is more absolutely certain than that the flat grid aerial of Mr. Franklin casts a wireless shadow behind it. This implies that the field due to the currents in the reflector wires close behind the reflector wires is in opposition with the field at that point due to the currents in the aerial wires.

Hence the reflector wires form a perfect screen as far as backward radiation is concerned and a perfect reflector as regards forward propagation.

The mistake Mr. Tanasescu makes is in ignoring the fact that true radiation does not begin until a quarter wavelength away from the oscillator, and that the magnetic force is propagated initially with an infinite velocity.

At the moment when the aerial current is at its maximum the field due to it at the reflector wire, which is a quarter wavelength away, is also a maximum, and the rate of change of this field and therefore the inducing E.M.F. is at a maximum. Hence even if the section of the reflector wire acts as a pure resistance and its current is in step with the E.M.F. the reflector current must be in opposition as regards phase with the aerial current. The radiation of magnetic force from the aerial wires begins to be propagated a quarter of a

wavelength from them with the velocity of light and the same for the reflector wires fields. Hence, at any distance along the line normal to the plane of the aerial, these forces differ in phase by 90 degrees.

In the direction of the plane of the aerial this difference is 180 degrees.

As we are only considering propagation nearly normal to the aerial, we can approximately take this difference of phase at the same place to be 90 degrees.

I need not deal in detail with the rest of his criticisms as they are mostly beside the mark.

I take the opportunity to correct myself one error which may have confused readers. On page 388 in equation (4) I have taken F to stand for $sin\ (N\pi\frac{d}{\lambda}\ sin\ \theta)$ and G for $sin\ (\pi\frac{d}{\lambda}\ sin\ \theta)$. On page 389 I have unfortunately omitted *dashes* over the F and G in the expressions $L+F—G=X$ and $L+F—G+K=Y$. These should be $L+F'—G'=X$ and $L+F'—G'+K=Y$ where $F'=(N\pi\frac{d}{\lambda}\ sin\ \theta)$ and $G'=(\pi\frac{d}{\lambda}\ sin\ \theta)$.

The title of my article is an "approximate theory," and it makes no pretence to being an exhaustive one. All I desired was to bring out the fact that the directive and beam effect of this form of aerial essentially depends upon *interference*. The results of the simple theory are however in general agreement with the facts as stated by Senatore Marconi and also as I have heard them privately from the Engineers of the Marconi Company.

J. A. FLEMING.

The Audio-Transformer Problem.

To the Editor, E.W. & W.E.

SIR,—I wish to thank Mr. P. K. Turner for his further letter in your September issue and am sorry that, owing to an error of my newsagent by which that issue was delivered to me a fortnight late, I am delayed a month in offering him apologies for my unkindness.

Mr. Turner's statement that it *is* the case for him that "L_1 will be as large as we can make it" brings us, I feel, to the root of the matter. We all want satisfactorily to reproduce frequencies down to say 25 cycles, so I take his statement to mean that on a commercially practicable manufacturing basis the core size and winding spaces of the transformer will be so reduced as to result in the required primary impedance at 25 cycles being the maximum mechanically possible within the limits of fine winding.

I would like, however, to ask Mr. Turner this question: "Supposing he were designing such a transformer without particular regard to cost, but with particular regard to good performance and with a moderate regard to size and weight, would it not then be the case that such a first-class transformer was such that its primary winding inductance was not the highest possible in the space occupied by that winding? Would he not use a rather larger core section and winding space, thereby obtaining the same inductance with a considerably reduced primary ohmic resistance? Could not self and mutual capacity effects be somewhat reduced by the greater freedom possible in the design of the windings?" In this connection it is to be noted that the reduction in the working flux density would compensate for the increased volume of iron in such a manner that hysteresis and eddy current losses would not be increased. In addition the H effect of the steady current would be reduced and this in itself would have the (secondary) effect of increasing the available inductance as well as the available amplitude of low frequency operation. Low frequency operation would also be assisted by the reduction of primary ohmic resistance.

Consider the effect of .

A 2 per cent. increase in all the linear dimensions of the iron and winding spaces.

This would give for the same inductance

A 1 per cent. decrease in the number of turns.
„ 3 „ „ „ flux density.
„ 4 „ „ „ primary resistance.
„ 3 „ „ „ steady H.
No change in eddy current loss.
No appreciable increase in hysteresis loss.
The secondary effect of higher inductance due to smaller steady H.

There is the one snag, viz., that, with similarly formed windings, the capacities would be increased 2 per cent. This is of no consequence on the primary. (Technically, therefore, the argument of larger size applies with great force to an *output* transformer, whose primary impedance *on open secondary circuit* must be several times that of the valve even at 25 cycles.) My suggestion is that the added liberty of design, resulting from the increased dimensions, would enable us largely to avoid the increases in the secondary and mutual capacities, and therefore to produce a transformer equally good on high and better on low frequencies and one for which L_1 is not as large as we can make it. It would if we keep the same number of secondary turns, also have a higher ratio and amplification.

I have no connection with any concern manufacturing audio transformers and no opportunity of making any but simple tests on these: my interest in them is purely scientific, and as such it seems to me that no firm has yet produced the really first-class article. Also that when it is produced, it will be such that L_1 is not as large as mechanically possible. I call to mind a make of audio transformer of which I believe this is true, which make I regard as the nearest approach to the ideal.

I shall await with interest further communications from your manufacturing correspondents showing me, if such is the case, that the production of a still better transformer on the lines suggested is impracticable on some other basis than the question of cost.

There is one other point arising out of Mr. Turner's letter, and that is that the equality principle as between effective primary impedance and valve impedance is still applicable, on the assumption of a perfect coupling, in the case of a loaded secondary of a fixed number of turns, when the primary is varied. In the stage case the load is considered to be a capacity in series with the secondary resistance, and in the output transformer case, a fixed speaker load connected to the secondary.

Derby. E. FOWLER CLARK.

To the Editor, E.W. & W.E.

SIR,—Now that the problem of the A.F. transformer primary has been settled, might we not consider the *secondary* ?

Some few makers put out a " 1st Stage " transformer of rather high ratio—some 5 : 1 or 6 : 1, with another for " 2nd Stage " of about 2 : 1. On close examination we find that these have identical primary windings, the idea of leaving out some of the secondary being to avoid overloading the output valve. Quite eminent manufacturers have adopted this system, and, of course, many little people have copied them without any clear idea on the subject. The practice does not appear to be quite sound : it is a dodge rather than a solution —alas, all too common in wireless !

So far as I can recollect, there was little science and no logic in the design of transformers available to the public up to about four years ago, when a very old-established firm in this country brought out a pair of transformers to suit the best valves then available ; it was evident that much thought had been given to the problem of the primary windings, and the ratios were such as to give good strength with plenty in hand, whatever the considerations were that led to the choice of the values. Other firms—some of whom should have known better—floundered along for years by rule of thumb, or no rule at all. Now that there is more general understanding of what a transformer should do, most makers seem to choose a primary winding to suit a given class of valve, and then fill up the rest of the space with secondary, subject to considerations of self-capacity, etc., but at least one firm keeps the same secondary winding through a whole series of instruments, varying the number of primary turns to suit the valve after which the transformer is to be used.

At first sight, one is inclined to agree with the school that " fills up the rest with secondary," subject to the obvious precautions, but are there not other factors which might influence design ? The opinions of people qualified to hold them should be of great interest.

Plympton, Devon. L. J. VOSS.

Amplification of Small Currents by Means of the Thermo-Relay.

To the Editor, E.W. & W.E.

SIR,—With reference to the article entitled " The Amplification of Small Currents by means of the Thermo-Relay, etc." in your October issue, will you kindly allow me to point out that the method described was evolved by me prior to 1919 and is fully described in my Patent Specification No. 144757 of 1919, and also in a paper read by Miss T. D. Epps and myself before the Physical Society of London. Vol. xxxii., Part V., p. 326, August, 1920.

At the time this method aroused little interest, and it is satisfactory to see that it is now receiving the attention it merits ; but I think it unfortunate that no acknowledgment of our work should be made.

All that Messrs. Moll and Burger appear to have done is to substitute their own particular form of thermocouple for those described in my patent.

Surbiton, Surrey. W. H. WILSON.

[From the following reprint from the *Proceedings of the Physical Society of London* to which reference is made in the letter, it will be seen that Mr. Wilson's priority in the matter is beyond question. It is unfortunate that no acknowledgment or reference to this earlier work was made by Dr. Taylor, but we presume that it was unknown to him. We were present when Mr. Wilson's paper was read in 1920 and subsequently used his method of making thermo-junctions for use in thermo-ammeters, but yet we had so entirely forgotten that he had suggested their use for magnifying galvanometer deflections, that we regarded Moll and Burger's suggestion as something quite new. We are pleased to know that the idea originated much nearer home than Utrecht.

From the *Proceedings of the London Physical Society*, Vol. xxxii., p. 338, 1920.

" Another useful arrangement consists of two lines of junctions connected in opposition and arranged close together as shown in Fig. 15. If radiant heat be arranged to fall in a line 1 mm. in width symmetrically about the axis *A-B*, the thermo-E.M.F.s generated in the two halves will be equal and opposite, but a movement of the heat line of ½ mm. to either side will cause it to cover entirely one set of junctions or the other, resulting in a deflection of the galvanometer from one side of zero to the other side of zero. Since the number of junctions in each line may be made large by these methods, the deflection of the galvanometer *G* may be made substantially proportional to the movement of the band of radiant heat.

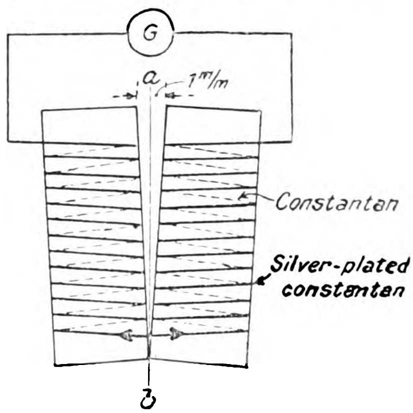


FIG. 15.

" The arrangement, therefore, comprises a useful means of magnifying small movements. The band of radiant heat may be the image formed by the mirror of another reflecting galvanometer, hence it is possible to cause a deflection produced by this galvanometer to produce a considerably larger deflection in the galvanometer *G* connected in the thermo-electric circuit."—ED., *E.W. & W.E.*]

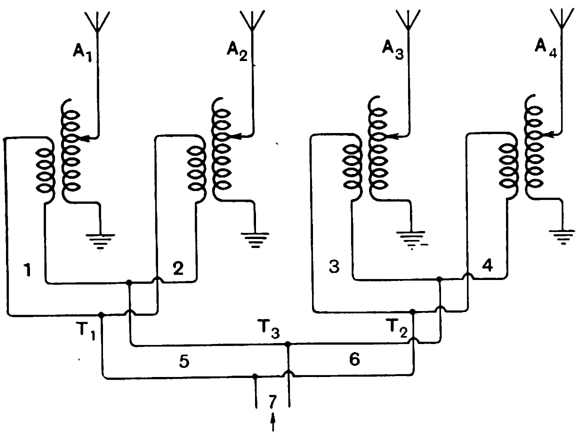
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

AERIAL FEEDERS.

(*Application date, 30th April,* 1926. *No.* 274,970.)

Extended aerial systems A - - - A_4, such as are used for directive "beam" transmission, are fed with high frequency currents at a number of points along their length as shown. In this connection difficulties arise owing to reflection effects occurring at the various junction points T_1, T_2, T_3 of the feeding cable, and the consequent creation of stationary waves. For instance, in any section of feeder cable in which the terminal load is not equal to the surge impedance of the line, stationary waves will be set up, but at points in the cable one-quarter wavelength apart, voltage and current will be in phase, and the net effect of the load and cable is that of a pure resistance.



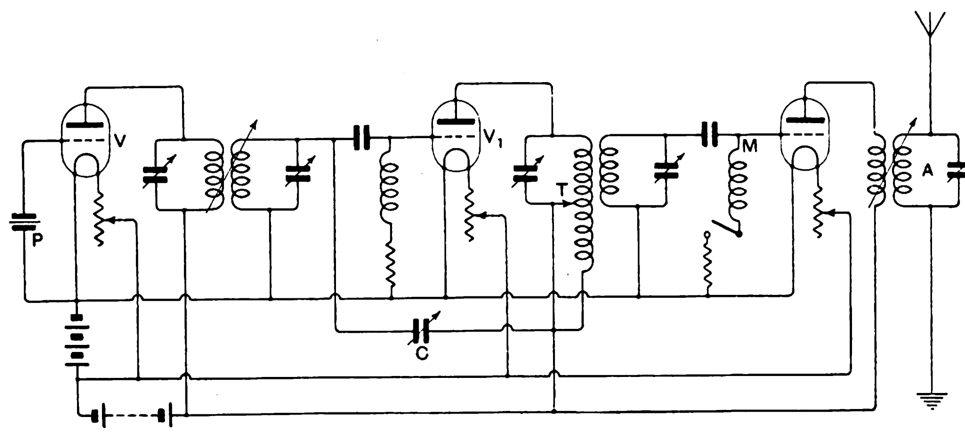
Advantage is taken of this fact to arrange the effective resistance to equal the surge impedance and thus avoid all reflection effects. The aerial loads are first adjusted so that there are no stationary waves set up in the Sections 1—4. The Sections 1 and 2 will however constitute a load upon the Section 5, equal to that thrown by the Sections 3 and 4 upon the Section 6. The invention consists in making the Sections 5 and 6 each an odd number of quarter wavelengths long, so that the effective load upon the junction T_3 becomes a pure resistance which can be made equal to the surge impedance of the line 7.

Patent issued to E. Green.

FREQUENCY STABILISERS.

(*Application date, 18th August,* 1926. *No.* 274,660.)

In the ordinary method of coupling a crystal-controlled oscillator to successive stages of amplification, a temporary breakdown of the crystal oscillator usually results in the transmitting gear being placed out of action. In order to overcome this difficulty the master-control valve V, containing a piezo-crystal P in its grid circuit, is coupled to a valve V_1, which is itself capable of generating sustained oscillations through the interaction of tuned plate and grid circuits. By a back-coupling from the point T through a condenser C, the valve V_1 is neutralised to such an extent that so long as the crystal P is in operation, only those oscillations of predetermined frequency are passed through to



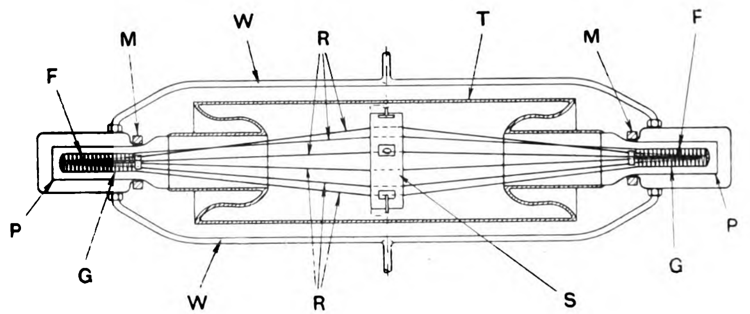
the modulator M and aerial A. Should the crystal break down, however, the neutralising means can be readjusted to the point where the valve V_1 itself generates oscillations sufficient to maintain transmission, independently of the frequency control stage V.

Patent issued to C. W. Goyder.

SHORT-WAVE GENERATOR.

(*Application date, 13th April,* 1926. *No.* 274,183.)

The multi-electrode tube illustrated has been designed to generate high frequency oscillations varying from ten million up to several hundred million cycles per second. In order to obviate the enormous capacity leakages occurring at the higher ranges, the whole of the circuit connections, including a part of the radiating system, is enclosed within the same evacuated vessel as the tube electrodes.



The two co-acting sets of electrodes P, F, G are mounted at the opposite ends of a sealed tube T, and are connected in pairs by a series of straight rods R. The anodes are water-cooled, the cooling liquid circulating through pipes W. A central steatite member S, mounted inside the vessel T, forms a support for the rods R, and also constitutes the point at which the filament voltage is supplied to the system. The anode voltage is applied through the water pipes W.

The generated high frequency oscillations are located partly in the internal rods R joining the two grids, and partly in the external water tubes W connecting the plates. Radiation may take place directly from the tube system, but the latter is preferably coupled inductively to a separate tuned radiator. Guard rings M protect the glass seal of the containing vessel from the effects of high frequency electric stress.

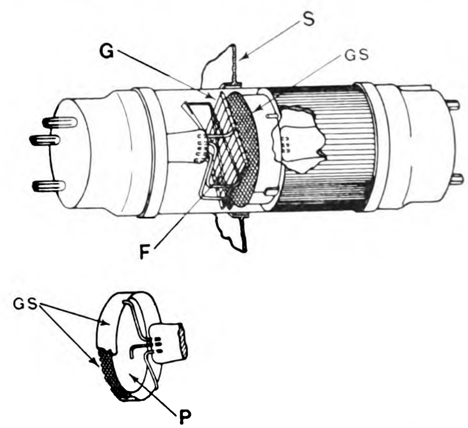
Patent issued to W. J. Brown and Metropolitan Vickers Co.

SHIELDED GRID VALVE.

(*Application date, 5th May,* 1926. *No.* 275,335.)

In order to eliminate the effect of inter-electrode capacity between the plate and grid circuits of an amplifying valve, an additional grid is interposed between the ordinary control grid and the plate, and is designed to shield one from the electrostatic field of the other. As shown in Fig. 1, all four electrodes are arranged transversely to the glass tube, *i.e.*, one behind the other, as distinct from the ordinary arrangement in which the grid and filament are mounted inside a cylindrical plate.

The filament F is V-shaped and is mounted inside a flattened spiral winding G forming the ordinary control grid. Both these electrodes are supported from a glass foot at one end of the containing vessel. The shielding grid $G\,S$ consists of a disc of metal gauze fixed to a metal rim, the whole forming a bowl-shaped member (shown separately in the figure). The plate P consists of a plain disc of metal lying inside the periphery of the grid $G\,S$. These two electrodes are preferably mounted in a glass foot located at the other end of the containing vessel to that supporting the filament and control grid. Corresponding contact pins are provided at each end of the bulb as shown. In order to increase the shielding action of the grid $G\,S$, an auxiliary



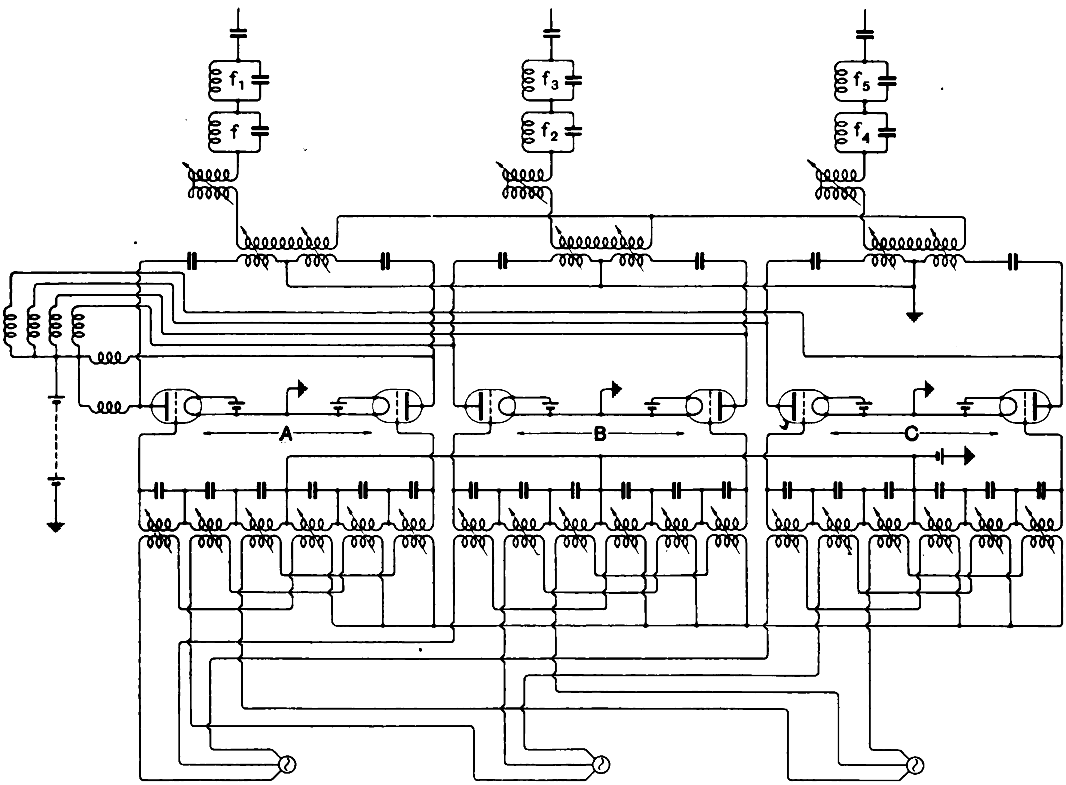
shielding member S, terminating in a flattened rim, is mounted outside the bulb and close to the grid $G\,S$. In operation this external member is directly earthed, whilst the shielding grid is given a biasing voltage of 80, assuming an operating voltage of 120 on the plate.

Patent issued to H. J. Round.

"POLYPHASE" WIRED WIRELESS.

(*Convention date* (*U.S.A.*), *23rd December*, 1925. *No.* 263,777.)

Wired Radio Inc. propose to use triphase carrier current, each phase of which is separately modulated, for distributing alternative broadcast programmes



simultaneously by wired wireless. The mains of a polyphase power-transmission system from the distributing network.

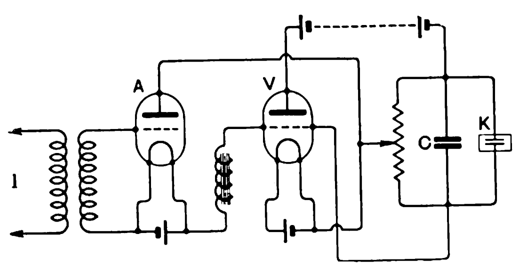
As shown in the figure, modulated carrier frequencies f_1, f_2, f_3 are fed from triphase generators, 1, 2, 3 to the input circuits of three pairs of balanced H.F. amplifiers *A*, *B*, *C*, the coupling-coils being arranged as shown in order to suppress the even harmonics. Other harmonics are eliminated by filter circuits f_1 . . . f_5 in the outgoing network.

PHOTO-ELECTRIC APPARATUS.

(*Convention date* (*Germany*). *18th August*, 1925. *No.* 257,268.)

The so-called Kerr effect relates to the rotation of plane polarised light when reflected from a magnetised surface. A similar rotation occurs when passing a ray of light through a cell containing carbon bisulphide placed in an electrostatic field. It is obvious that such an arrangement may find a useful application in television and similar apparatus where the conversion of electric currents into corresponding optical effects is involved.

According to the present invention the normal sensitivity of a Kerr cell is increased by subjecting it to the influence of high frequency oscillations, in addition to the low frequency signalling impulses. As shown in the figure a Kerr cell *K* is bridged



across a condenser *C* in the plate circuit of a back-coupled valve *V*, generating oscillations of the order of 10^6 cycles per second. Low frequency impulses,

corresponding to the "picture elements" or other signals are applied at *I* through an amplifier *A*, inserted across the grid and filament of the generator *V*.

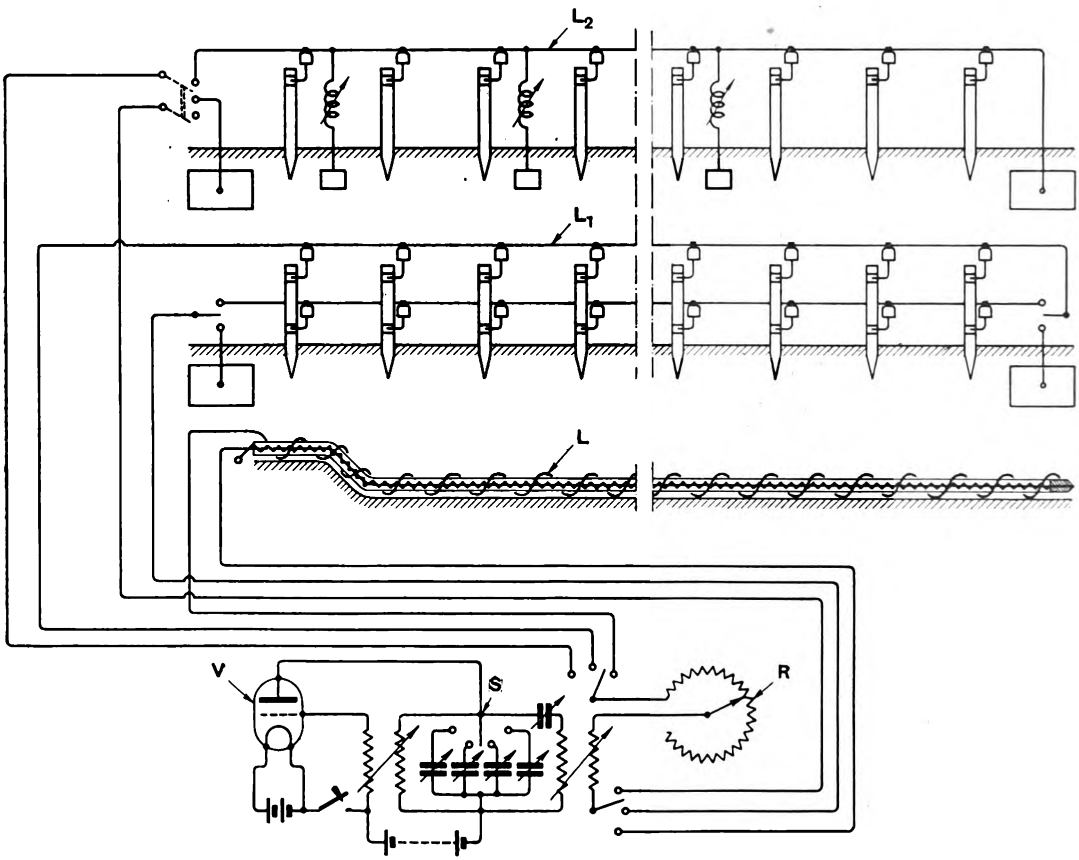
Patent issued to the Telefunken Co.

CABLE LEADER GEAR.

Convention date (France), 15th April, 1925. No. 250,933.)

The navigation of tortuous channels by ships, or the landing of aeroplanes at night or in foggy weather, can be assisted by means of a system of cables fed with low frequency current. The cables are laid along the course to be followed, and their location is detected by picking-up the spreading inductive fields due to the low frequency currents. For this purpose a valve amplifying set is carried by the vessel under navigation.

According to the present invention currents of different frequencies can be fed, either simultaneously or successively, into a submarine line *L*, or into overhead "leader" cables L_1, L_2 from a single oscillating valve *V*, comprising a number of differently-tuned circuits, which can be brought into operation at will by means of a switch *S*. An automatically-rotating rheostat control arm *R* can be used to vary the intensity of the currents fed into the "leader" cables, thus giving the navigator an opportunity of gauging his actual distance from, as well as his bearings relatively to, the guide cables. If, for instance, the current supply is maintained at constant strength, a constant range of reception from any given point results. When however the amplitude of the supply current is varied, the duration of the individual signal notes detected in the receiver will increase the nearer the observer approaches to the energised cable. In this way a shortening of the silent period between successive notes indicates that the vessel is closing-in towards the energised cable.



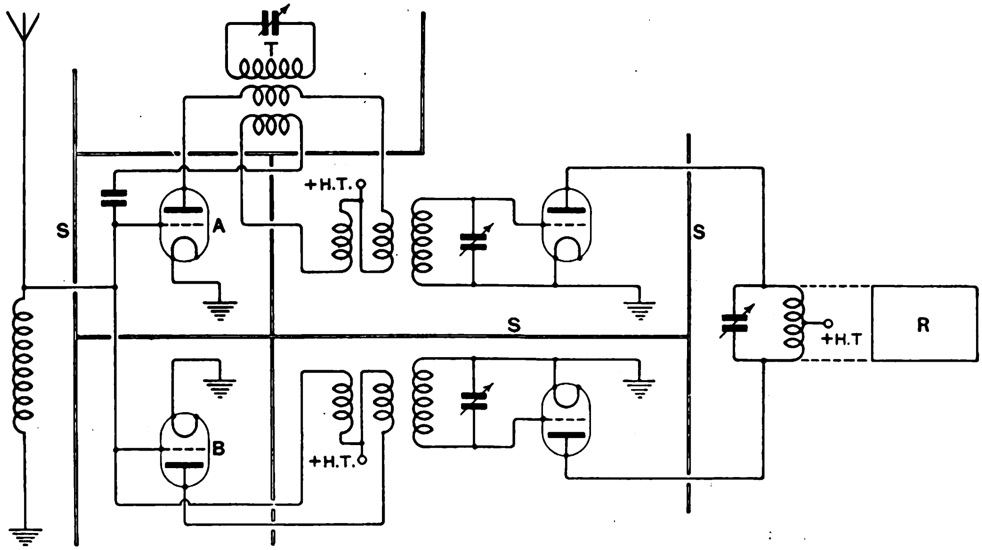
Patent issued to Société Industrielle des Procédés —W. A. Loth.

INTERFERENCE ELIMINATORS.

(*Application date, 30th October,* 1926. *No.* 276,195.)

The invention is based upon the known method of preventing interference in which two separate circuits are fed from the same aerial in such a way

that one circuit transfers the interference effects only, whilst the other circuit transfers both the desired signal and the interference. By opposing the outputs from the two circuits in a common receiver, the interference effects are cancelled out, leaving the desired signal alone to reach the detector. The inventor points out that the inter-electrode capacity of the relay valves used in such a system is a disturbing factor, and claims the use of suitable neutralising and screening means to prevent interaction between the circuits.



As shown in the figure two separate branches *A* and *B* are provided between the aerial and the common receiver *R*, the valves being suitably balanced for capacity coupling and shielded by metal screens *S*. The branch *B* transfers both the desired signals and interference. A wave trap *T*, tuned to the desired signal frequency, is coupled to the branch *A*, and absorbs the desired signal component from that circuit. The result of combining the two outputs is to cancel out the common component of undesired frequency. The residue is the desired signal and appears alone in the detector *R*.

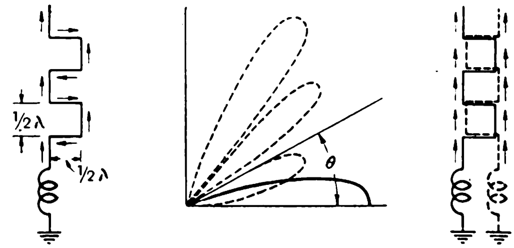
Patent issued to R. Custerson.

SHORT-WAVE AERIALS.

(*Application date*, 10*th March*, 1926. *No.* 267,540.)

The antennæ system comprises wires or layers bent at right angles in sections corresponding to half wavelengths as shown in Fig. 1. To an observer located on the horizon, in a line perpendicular to the plane of the aerial, the vertical current components indicated by the arrows are additive in phase, since they are all at approximately the same distance from him, so that the vertically polarised electric field will be at a maximum. Should the observer now move upwards, say in a balloon, still keeping perpendicular to the plane of the aerial, the vertically polarised field will be found to be distributed as shown in the shaded polar diagram of Fig. 2, whilst horizontally polarised fields will be discovered having the distribution shown in dotted lines in Fig. 2.

If the observer moves out of a line perpendicular to the plane of the aerial the distribution of the vertical and horizontal fields will greatly change, owing to the increase in effective distance between successive elements of the bent aerial. In all cases, however, such an aerial system is characterised



(1) (2) (3)

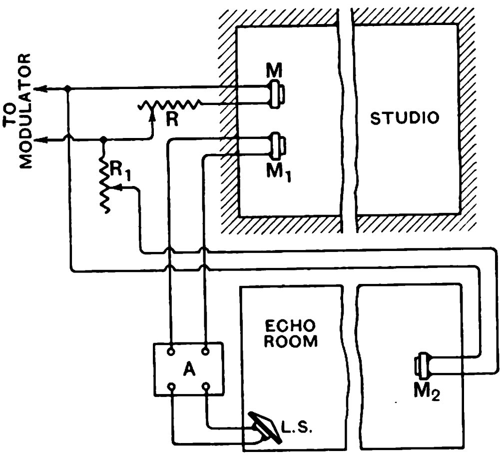
by the radiation of energy in which the polarisation of the electric field changes suddenly according to the position of the receiver. Fig. 3 represents a combination of two bent aerials in which the effect of the horizontal segments is neutralised. The principle is also applied to aerials bent in three dimensions.

Patent issued to Société Française Radio-Electrique.

REVERBERATED BROADCAST.

(*Application date, 13th May*, 1926. *No.* 276,052.)

In order to subdue the "first echo" effect to pleasing proportions, it is usual to drape the walls of the broadcasting studio. This, however, robs the transmission of the subtle quality of the more prolonged echoes or reverberations, and produces a somewhat "dead" tonality at the receiving end. The object of the present invention is to overcome this defect by restoring the missing reverberations, which are produced separately in an undraped room at a distance from the studio proper.



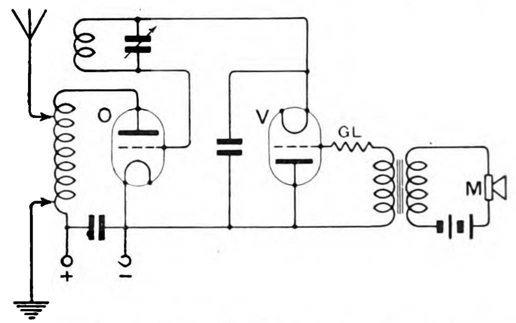
As shown in the figure two microphones marked M, M_1 are provided in the studio. The first feeds the modulator circuit directly, whilst the second is connected through an amplifier A to a loud-speaker located in the "echo" room. In the same room is a third microphone M_2 so situated as to receive the reverberations set up in that room, whilst avoiding as far as possible any direct pick-up from the loud-speaker. The current from the microphone M_2 is fed into the modulator circuit in parallel with that from the main instrument M, the relative strength of the direct and "reverberation" components being adjusted by means of rheostats R, R_1.

Patent issued to H. J. Round.

GRID-CONTROL MODULATION.

(*Application date, 8th July*, 1926. *No.* 275,771.)

The output from a power valve O is modulated by varying the conductivity of an auxiliary valve V, which is inserted in the grid-filament circuit of the former and functions as a grid-leak. Modulating current from the microphone M is applied across the plate and grid of the valve V. A high resistance $G\ L$ of the order of 90,000 ohms is inserted in series with the secondary winding of the microphone transformer, and serves to regulate the grid potential of the valve V, so that its internal impedance is automatically controlled throughout the whole range of the applied modulating voltage. In an alternative arrangement the resistance $G\ L$ is omitted, and a third valve is shunted across the plate and grid electrodes of the valve V, the microphone voltage then being applied across the grid and filament of the added valve.

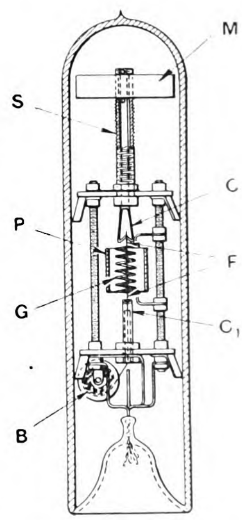


Patent issued to N. F. S. Hecht and G. Morton.

RENEWABLE VALVE FILAMENTS.

(*Convention date* (*France*), *22nd June*, 1926. *No.* 273,293.)

A supply of tungsten wire is mounted on a bobbin B inside the casing of the valve, and means are provided for replacing a burnt-out section of filament without breaking the seal. The active portion of filament is held between two clips C, C_1, the upper of which can be made to move downwards into contact with the lower by rotating a soft-iron member M along a screwed spindle S under the influence of an external magnet.



When the filament burns out, the upper clip C is accordingly brought down through the spiral grid G and plate P until it reaches the conical nose of the clip C_1. Further movement causes the clip first to open and release the old end of wire, and then to take a fresh grip on the remaining piece of tungsten projecting from the clip C_1. On its backward movement a new length of filament is drawn from the bobbin B, the pressure of the clip C_1 on the wire being less than that of the clip C in order to allow the wire to slip through.

Patent issued to C. Tourne.

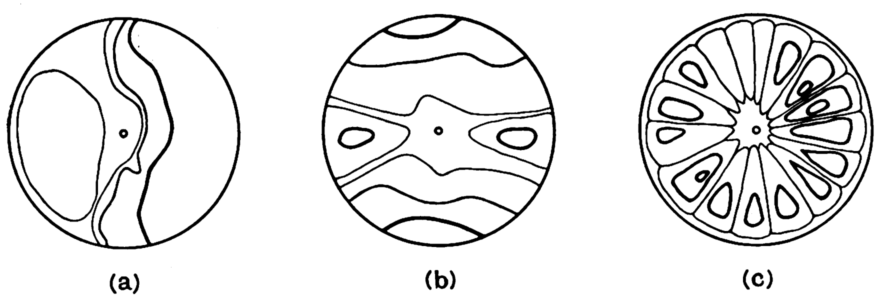
EXPERIMENTAL WIRELESS & The WIRELESS ENGINEER

VOL. IV. DECEMBER, 1927. No. 51.

Editorial.

The Vibrations of Loud-Speaker Diaphragms.

IN a loud-speaker of the cone type the mechanism moves the centre backwards and forwards at a frequency corresponding to the pitch of the note and with a complexity of movement depending on the character of the sound being reproduced. We feel sure that we are correct when we say that most people who use such a loud-speaker picture the whole diaphragm moving backwards and forwards with the central S. Hill of Standard Telephones and Cables, Ltd., and published in a recent number of *Electrical Communication*. The type of loud-speaker will be familiar to most readers. It consists of two cones of brown hand-made bookbinding paper about 18 inches diameter, cemented together at their bases; the back cone is truncated and clamped to a frame, whilst the apex of the front cone is clamped to the driving rod.



(a) *Sand figure obtained when the "Kone" rocks about a diameter;* (b) *Sand figure given by sector vibration of the "Kone" at a frequency of about* 110 *cycles per second;* (c) *Sand figure given by sector vibration of the "Kone" at a frequency of about* 150 *cycles per second.*

driving pin or coil, the extent of the movement naturally decreasing as one passes outwards from the centre to the periphery. Anyone holding such views will be very surprised at the results of some experiments made on a "Kone" loud-speaker by Mr.

The modes of vibration were observed by placing the loud-speaker horizontally and sprinkling sand on it while it was energised by a steady alternating current of single frequency. The sand is thrown off the vibrating portions of the surface and

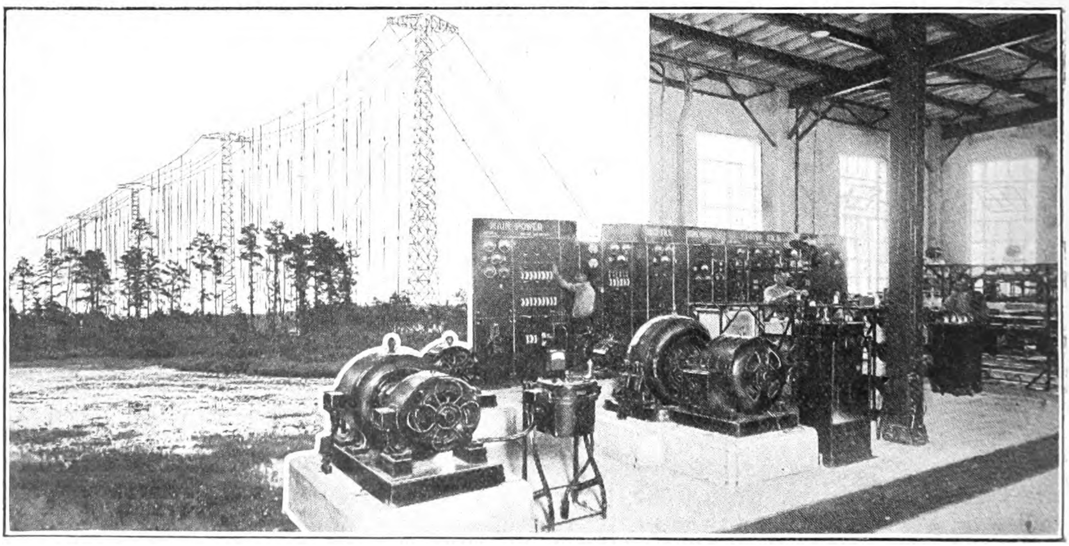
accumulates along the nodal lines separating two portions of opposite phase. The experiments showed that there were four distinct types of vibration, depending on the frequency of the alternating current, and that none of them corresponded to the simple vibration of the diaphragm as a whole, although it is mentioned as a possibility at very low frequencies. The type that occurs at frequencies from these extremely low ones up to 100 cycles per second is shown in Fig. (*a*); it is mainly a rocking vibration about a diameter but by no means a simple rocking.

The second mode of vibration sets in just above 100 cycles per second; the diaphragm is split up into a number of sectors, the number increasing rapidly with the frequency. At a frequency of 110 there are four sectors as shown in Fig. (*b*) where, however, the diametral vibration still seems to predominate; at 150 cycles per second the number of sectors has increased to 16 as shown in Fig. (*c*). In this case, however, there is still considerable irregularity, some sectors showing single, some double and some well pronounced triple vibrations. It is a pity that no indication is given in the diagrams of the position of the cemented join in the paper, nor of the relation of this join to the position of the mechanism; these details would probably throw some light on the striking want of symmetry and regularity in the results.

Above about 150 cycles per second the radial sectors begin to break up into smaller patches; this goes on with decreasing size of the individual patches up to about 800 cycles per second, above which the diaphragm vibrates in a number of annular rings.

The fairly uniform response of this type of loud-speaker over a wide range of frequencies is due to the multiplicity of its modes of vibration, each having its own resonant frequency, but one mode merging into another as the frequency is varied. It is interesting to consider the complexity of the resulting vibration of the diaphragm when it is reproducing at a given moment every instrument in an orchestra and doing it so truthfully that one can pick out each instrument by its characteristic tone.

The Beam System in U.S.A.



Rocky Point Beam Station equipment. The aerial system for the beam transmitter is shown on the left, and on the right a general view of the generator room.

Some Experiments with Side-Band Telephony on Short Wavelengths.

By E. Howard Robinson.

A SIMPLE outline of the principles of side-band telephony was given in one of the first issues* of this journal, and has also appeared in various issues of the *Proceedings of the Institute of Radio Engineers*.† The essential feature of side-band radio telephony consists in removing the steady carrier component from the transmission and sending out either one or both of the side-bands. The carrier component, which is necessary for efficient and intelligible reception, is supplied at the receiver by a small local oscillator adjusted to the correct frequency. The chief advantages are great economy in power and size of transmitting valves at the transmitter for a given intensity at a distant receiver, and also the reduction of interference with receiving stations listening to some other transmission on a neighbouring wavelength.

The object of the experiments described here was to ascertain whether the advantages of side-band transmission could be realised on wavelengths of about 200 metres or less. From the start it was not even hoped that there would be any possibility in this particular series of experiments of isolating only one side-band. It was considered that useful work would have been done if satisfactory two-side-band transmission were accomplished; even the possibility of this was considered remote, as the only carrier-eliminating systems known at the time were virtually bridge methods, which are very difficult to balance at high frequencies.

The existing system, due to J. R. Carson,‡ was tried on the experimental bench, but it was very soon found that even with a carrier frequency corresponding to a wavelength of 450 metres it was a very tricky proceeding to balance out the carrier component completely. The Carson system employs two balanced modulator triodes, to the grids of which both H.F. drive and L.F. speech voltages are applied. If there is complete symmetry both in the valves themselves, and in the differential output circuit the carrier does not appear in the output, but the necessary symmetry is difficult to attain on frequencies of the order of 1.5×10^6, as it is essential not only to pick two valves of substantially identical characteristics, but to compensate for small differences in inter-electrode capacity and any residual differences in characteristics. Even then the carrier is apt to creep into the output again as the valves warm up and disturb the initial balance. Further, this system gives only a very limited side-band output for the size of valves used in the modulator. Operation must be limited strictly to the curved portion of the grid-voltage anode-current characteristic, otherwise the whole theory of the modulator falls to the ground.

Fortunately it was possible to devise a totally different and more efficient carrier-suppressing modulator. In order to understand clearly the principle on which the system works let us consider briefly the nature of two side-bands alone as compared with the usual two side-bands plus carrier. Suppose we start with an oscillator giving an H.F. carrier voltage $V_0 \sin \omega t$, and modulate its amplitude V_0 by $100 \times m$ per cent. with a low frequency $\omega_1 2\pi$; we obtain oscillations of the form:

$$(V_0 + mV_0 \sin \omega_1 t) \sin \omega t$$

$$= V_0 \sin \omega t + mV_0 \sin \omega_1 t \sin \omega t$$

$$= V_0 \sin \omega t + \frac{mV_0}{2} \cos (\omega - \omega_1) t - \frac{mV_0}{2} \cos (\omega + \omega t)$$

(This is illustrated graphically in Fig. 1 (a).)

*E.W. & W.E., Vol. 1, No. 2. "Side-Band Telephony," by E. H. Robinson.

† Proc. I.R.E., Vol. 11, No. 1. "Relations of Carrier and Side-Bands in Radio Transmission," by R. V. L. Hartley. Proc. I.R.E., Vol. 13, No. 3. "Production of Single Side-Band for Trans-atlantic Radio Telephony," by R. A. Heising.

‡ See E.W. & W.E., Vol. 1, No. 2.

The last two terms of the latter expression represent the two side-bands, and if we can eliminate the carrier component $V_0 \sin \omega t$, we are left with the two side-bands, which can be expressed by :—

$$mV_0 \sin \omega_1 t \sin \omega t \qquad \text{(See Fig. 1 (b).)}$$

This simply represents an H.F. oscillation whose amplitude is itself a simple harmonic

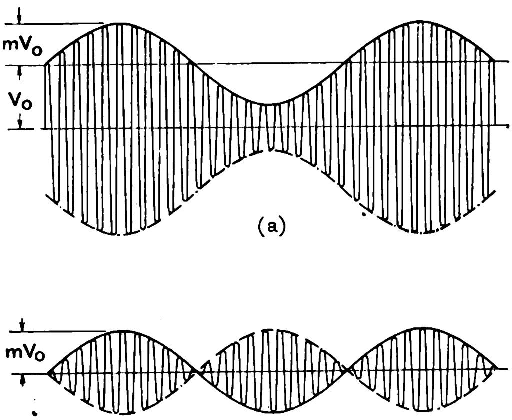


Fig. 1.

function at a low frequency. Now this means that if we can obtain a generator of H.F. oscillations whose amplitude is algebraically proportional to the instantaneous input, and if we supply such a generator with pure A.C. telephonic power input we shall get an H.F. output consisting entirely of two side-bands with no carrier component at all. An ordinary valve oscillator without any D.C. on the anode, but supplied from an audio-frequency transformer, would not be any use, of course, since it would only function on one-half of the cycle.

The system shown schematically in Fig. 2, and known among radio amateurs as the "self-rectifying" circuit, was tried. It will be seen that on either half cycle one of the valves must be operative. The system did not give the desired result ; it gave neither proper side-band output nor anything else of any use. The reason for this is an important and fairly obvious one. In the case of a normal pair of side-bands the H.F. amplitude, $mV_0 \sin \omega_1 t$, being a sine function, is alternately positive and negative ; when the modulation cycle passes through zero the H.F. oscillations undergo a phase change of 180 degrees. Figs. 1 (a) and (b) help to make this clear graphically : (a) represents ordinary modulation, *i.e.*, carrier plus two side-bands, while (b) represents two side-bands alone. The envelope of the positive half-cycles in (a) is shown by the full line, and that of the negative half-cycles by the dotted line. Now, to derive the graphical representation of two side-bands alone from (a) we must subtract the instantaneous carrier amplitude V_0 from every point of the H.F. cycles. This gives us directly Fig. 1 (b), in which the full positive envelope line alternately goes on the negative side of the zero line. The system in Fig. 2 does not give this 180 degree phase reversal, both valves giving the same phase of excitation in the output circuit with respect to the grid drive.

Fig. 3 shows the modified circuit giving the required phase reversal. The point of

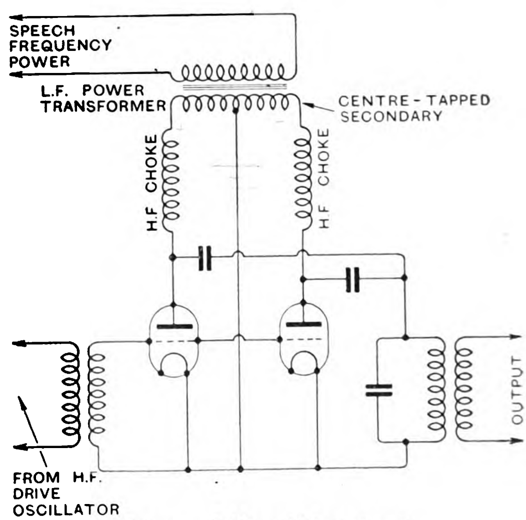


Fig. 2. *Self-rectifying circuit.*

difference from Fig. 2 is that there is a centre-tapped tuned anode circuit, the anodes of the two valves being connected to opposite extremities of this circuit. The grids of the valves are connected in parallel, and driven with a constant H.F. voltage of the required carrier frequency. It will be seen, therefore, that each time the speech frequency voltage across the L.F. power transformer

passes through zero a different modulator valve comes into operation, and the H.F. phase in the output is reversed. An independent drive oscillator is used in preference to making the modulators a self-oscillating system, in order to avoid phase irregularities and threshold discontinuities each time the anode supply passes through zero.

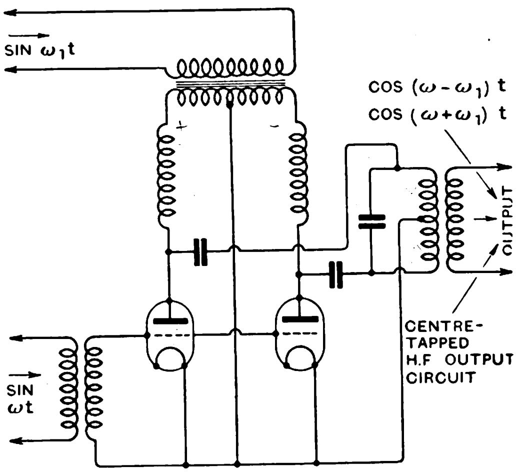


Fig. 3. *Modified circuit to give phase reversal.*

The system in Fig. 3 was found to be an immediate and complete success. It produces two side-bands minus carrier as easily and copiously as ordinary choke control produces "straight" telephony. Besides being a modulator system it is an H.F. power amplifying stage of reasonable efficiency. It is self-neutralised, and, therefore, quite stable. No trace of carrier wave appears in the output. Critical balancing is not necessary, but the two valves must be reasonably similar, and the centre-tapped L.F. and H.F. windings must be as symmetrical as conveniently possible. There would appear to be no lower limit to the wavelength upon which the system will work. The limit would be set rather by the difficulty of homodyne reception on very short wavelengths.

Practical Details of Experiments.

A transmitter was set up at a location in N.W. London. Details of the circuit arrangements are shown in Fig. 4. The master oscillator V_1 was an ordinary high impedance receiving valve ($\mu=35$), namely, a "Cosmos" SP55B, with an anode supply of about 100 volts. The quartz plate Q lay on a flat copper plate A, and on the upper face of the crystal a brass disc B $\frac{5}{8}$ in. diameter was allowed to rest. The .25 megohm Varley wire-wound resistance R_1 served to maintain the normal grid potential of V_1 about equal to that of the negative filament lead. The crystal Q had a main natural frequency corresponding to a wavelength of 194 metres, this being the wavelength used throughout the experiments. The anode circuit $L_1 C_1$ was tuned to this frequency, no further reaction coupling being needed to maintain oscillations. A coil L_2 was just sufficiently coupled to L_1 to give the required drive on the grids of V_2 and V_3. Both L_1 and L_2 were ordinary plug-in receiving coils, L_1 having thirty turns, and L_2 having sixty turns. The coupling between L_1 and L_2 requires a certain amount of care in adjustment. This coupling must be sufficiently great to ensure adequate voltage drive on the grids of V_2 and V_3 to deal with the highest probable L.F. anode voltages, but at the same time it was found that if the coupling is too tight the frequency of V_1 is wobbled slightly during modulation, in spite of the crystal control.

The modulators V_2 and V_3 were two Marconi DE5's, with their anodes shunt-fed through chokes L_7 and L_8 from the centre tapped transformer T_2. The anodes were connected through 0.001μF mica stopping condensers C_7 and C_8 to the ends of an inductance L_3 tuned to the carrier frequency with a 0.0005μF variable air condenser C_3. L_3 was a single-layer winding of 20 D.C.C. copper wire on a cylindrical cardboard tube four inches in diameter. The middle turn of this coil was connected to the common negative filament lead as shown. The grids of V_2 and V_3 were connected in parallel and given about 6 volts negative bias by means of some dry cells B_1 through the coupling coil L_2. The coupling coil L_4 for transferring the two-side-band output from L_3 to the grid of the power amplifier V_4 had about the same number of turns as L_3, but on a former of smaller diameter which would slip inside L_3 for coupling purposes. The coupling was made quite tight, L_4 being right inside L_3 and symmetrical with respect to its centre point. The main H.F. power

valve V_4 was a Mullard 0/150C, with 700 volts D.C. anode supply and a negative grid bias of about 35 volts from a battery B_2. The filament was heated with A.C. from a suitable transformer working off the 50 cycle mains. The anode of V_4 was series fed through the centre point of the tuned anode circuit L_5 C_5, tuned to the carrier frequency (λ=194 metres). This circuit was centre-tapped to provide the necessary circuit calls for no comment, as it was quite conventional. The aerial current meter H only registers, of course, during modulation.

The low frequency side of the transmitter was straightforward enough. The microphone M was of the ordinary commercial inset type, which gave quite good enough speech quality for the purposes of the experiments. The microphone transformer T_1 had a step-up ratio of about 50 : 1. Since

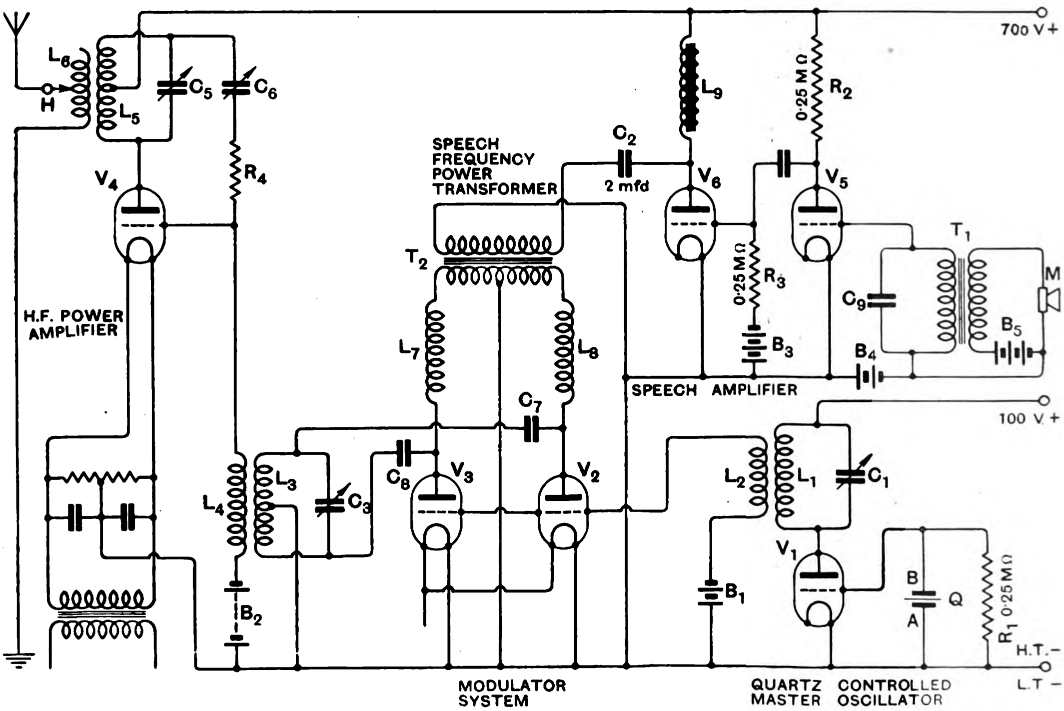


Fig. 4. *Details of transmitter circuit set up in N.W. London.*

neutralisation through the condenser C_6. This neutralisation is most essential as V_4 must, of course, have no tendency to oscillate on its own. C_6 need have only a very small capacity (about that of the inter-electrode capacity of V_4), but requires very careful adjustment. It was found that even when the system was neutralised with respect to the working frequency there was a strong tendency for oscillations at about 5 metres to be set up round the short path via C_5 C_6, grid and anode of V_4. This was stopped by insertion of a resistance R_4 in series with C_6; R_4 was about 100 ohms and took the form of an old carbon filament lamp. The aerial the main H.T. supply of 700 volts was used also for the L.F. amplifier it was convenient to use resistance coupling for the first stage V_5, which was a DE5B with a .25 megohm wire-wound anode resistance R_2. The final audio-frequency stage has, however, to produce several watts of audio-frequency power, since it is this power alone which feeds the anode circuits of the modulators V_2 and V_3. For this reason the second L.F. amplifier V_6 was an Osram DET1 with the full 700 volts on its anode and about 60 volts negative grid bias. The speech-frequency power transformer T_2 was virtually a 1 : 1 inter-valve transformer, with

2,000 turns on the primary and 2,000 turns on each half of the secondary. The core was closed, and had a cross-sectional area of one square inch; the design is not claimed as ideal, but it served its purpose. It will be noticed that a condenser C_2 and choke L_9 are used to keep the D.C. out of the primary of T_2. This is not absolutely essential, but seems to assist in obtaining a symmetrical output from T_2. The writer has noticed that when the primary of a small inter-valve transformer is connected directly in the anode circuit of the last power stage of a speech amplifier an asymmetrical voltage may be produced across the secondary, *i.e.*, the alternate half-cycles have different peak potentials. A more symmetrical output for the secondary of T_2 seems to be obtained with the arrangement shown.

It is rather difficult to rate the power of such a transmitter on the ordinary basis, as H.F. power is only generated as demanded by the modulation. If the main valve V_4 were allowed to oscillate on its own the H.F. power produced would be about 20 to 30 watts. The power dissipated on the anode in the absence of modulation was about 50 watts, but since the whole of the useful part of the characteristic could be used in accommodating the side-band components the transmission was equivalent to that from an ordinary system employing about 120 watts.

Too much emphasis cannot be laid upon the necessity for absolute constancy in the frequency of the oscillations generated by the master oscillator. One or two cycles frequency shift on the part of the master is quite enough to produce objectionable beats at the receiver in the case of a two-side-band transmission. On the wavelengths tried a quartz-controlled master oscillator valve was found to be practically a complete solution, and to all intents a necessity. Passably good results have, however, been obtained with a self-driven master, but very special precautions were necessary, chief of which were very loose coupling to the master oscillator, and the interposition of a carefully neutralised stage of H.F. amplification between the master oscillator and the modulator grids.

The correct H.F. drive for the grids of the modulators V_2 and V_3 was found by trial, the coupling between L_2 and L_1 being varied until best all-round results were obtained. With ample drive on these grids there appeared to be no trouble from "threshold effect." The smallest background noises were transmitted in due proportion in spite of the absence of carrier.

The circuit of the receiver used is shown in Fig. 5. The receiver itself calls for little

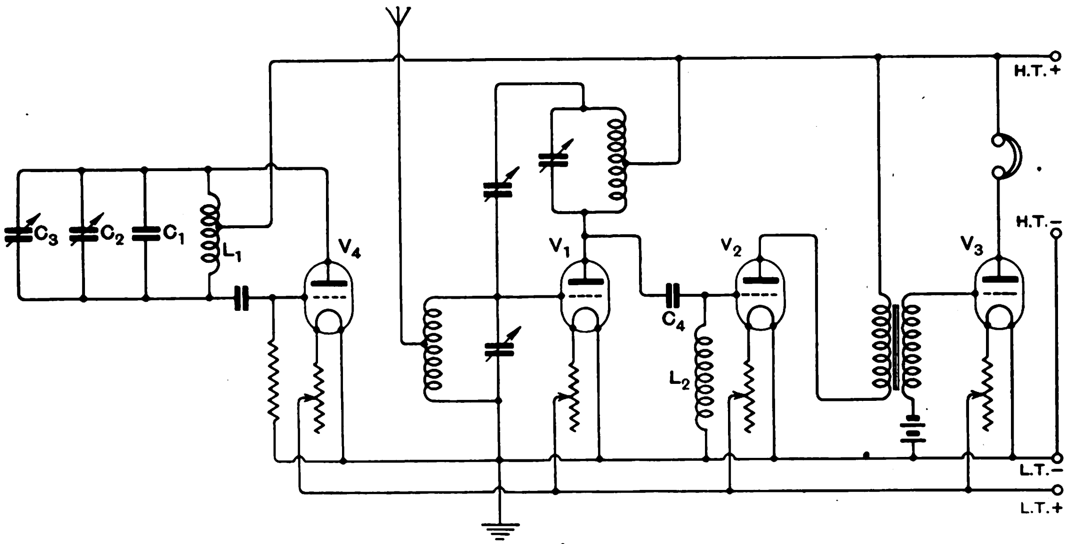


Fig. 5. *Circuit of receiver used.*

comment, as it is quite conventional. There is one stage of neutralised tuned anode H.F. amplification using a DE5B (V_1) followed by an anode-bend detector V_2 and one stage of transformer-coupled L.F. amplification. V_2 was an SP55B, and V_3 a DE5, the untuned H.F. choke L_2 is simply for the purpose of biasing the grid of V_2 for anode-bend rectification. Incidentally, it may be noted that neutralised H.F. amplification is very effective for the reception of telephony between 150 and 200 metres, and its ability to amplify to a really useful extent is beyond question. The homodyne oscillator V_4 was a simple Hartley circuit oscillator, V_4 being a DE5. The condenser C_1 was comparatively large, having a capacity of 0.0035μF, and correspondingly small inductance L_1 of copper strip was used. L was, in fact, a small transmitting helix. The object of using a large C to L ratio is to minimise the effects of variable stray capacities upon frequency, and also to reduce to a negligible magnitude variations due to changes in internal resistance of the valve. C_1 and L_1 together nearly tune to the carrier frequency of the transmitter. ($\lambda = 194$ metres.) The 0.0005μF variable condenser C_2 parallel with C_1 brought the homodyne within about a kilocycle of the carrier frequency, while the 0.00005μF condenser C_3, fitted with a long extension handle, allowed final adjustment to zero beat frequency between homodyne and carrier. The homodyne adjustment was the most troublesome feature in the whole system. Even when stray capacity effects have been eliminated troubles due to self and mutual inductance variations are apt to make their appearance. L_1 must be so loosely coupled to the receiver that "pulling" effects are substantially absent.

The arrangements described above gave such promising results on first tests that another similarly equipped transmitter and receiver were set up near Rickmansworth about twenty miles away from the first station.

Observations on Effects noticed in Working.

Two-way side-band was accomplished quite readily on a wavelength of 194 metres, but no true duplex working was attempted. When a two-side-band transmission is received with a non-oscillating receiver and no local heterodyne, it is mostly unintelligible, although familiar phrases are sometimes recognised. Something is heard, of course, but the intensity without the homodyne is relatively weak, and the sounds heard have a mumbling, scratchy quality. When the homodyne is brought into action, however, and is properly adjusted, the strength of the received speech is greatly increased, and the quality is as good as with any normal transmission.

It is not safe to consider the side-band transmission as a system of "secret telephony." A good deal is heard on a non-oscillating receiver which allows the meaning of some of the transmitted phrases to be understood. The rhythm and part of the intonation are, for instance, largely preserved. Further, although all fundamental tones are in theory absent until the heterodyne is used, it is often found that the fundamentals are heard to some extent without the heterodyne. One of the reasons for this would appear to be that in practice any note or tone contains harmonics as well as the fundamental and the side-bands due to these harmonics heterodyne mutually at the receiver to reproduce the fundamental. Also, any departure from symmetry in the modulator system appears to introduce some element of intelligibility, although the system is still a quiescent one. During one transmission the writer found that his speech was being read and understood quite well by several receiving stations using perfectly ordinary receivers. This was traced to asymmetry in the speech transformer T_2 (Fig. 4) and when this matter was rectified the speech became normally unintelligible on an ordinary receiver. The reason for this is at present a little obscure.

There is some difficulty in tuning in a side-band transmission for the first time; since no carrier is emitted, and the operator at the receiver finds it puzzling to decide when his homodyne is adjusted to zero beat frequency with respect to the master oscillator at the transmitter. When the homodyne is within a few cycles of the correct frequency, speech is received fairly clearly, but with a superimposed ripple equal to the discrepancy between carrier and homodyne frequencies. Once this stage has been reached by trial the discrepancy can be brought practically to zero by use of the fine adjustment. (C_3 in Fig. 5.)

These experiments showed quite unmistakably that on a wavelength of 194 metres the carrying power of a given wattage is greatly increased by the use of a two-side-band transmission instead of an ordinary one. When the valve V_4 in Fig. 4 was made to self-oscillate on the same anode voltage and was choke-controlled in the ordinary manner the signals received at a distance of twenty miles were considerably weaker than those obtained with the two-side-band system.

It is concluded from these experiments that there are considerable possibilities in side-band systems for short-wave telephony transmission. The great difficulty is the homodyne adjustment; it must be accurate to less than one cycle in a million, but this is not quite so impossible as it may sound. A one-side-band transmission would be much easier to receive, since it does not matter in this case if the homodyne is a few cycles out as far as speech is concerned. Unfortunately, it is much more difficult to isolate a single side-band and radiate it at a short wavelength. From the point of view of efficiency it is better to radiate two side-bands than one. (See Appendix.)

The side-band system certainly allows a very great saving of transmitting power and local interference. The subject is well worth the attention of amateur experimenters.

APPENDIX.

It is of great interest to decide upon the relative usefulness from the power-saving point of view of a single-side-band transmission and a two-side-band transmission. Let us consider both from the standpoint of the resulting effect at the receiver.

Two-side-band transmission.

Let the transmission produce at the receiver a wave represented by

$$\frac{A}{2} \cos(\omega - \omega_1)t - \frac{A}{2} \cos(\omega + \omega_1)t$$

Let the local homodyne add $B \sin \omega t$ where $B > A$. Resultant in receiver is :—

$$\frac{A}{2} \cos(\omega - \omega_1)t - \frac{A}{2} \cos(\omega + \omega_1)t + B \sin \omega t$$

$$= A \sin \omega t \sin \omega_1 t + B \sin \omega t$$

$$= \underline{(B + A \sin \omega_1 t) \sin \omega t} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Single-side-band transmission.

Let wave coming in from transmitter be represented by

$$A \cos(\omega - \omega_1)t$$

Let local homodyne add $B \sin \omega t$ where B is large compared with A.

Resultant in receiver is :—

$$A \cos(\omega - \omega_1)t + B \sin \omega t$$

$$= A \cos\left\{\left(\omega - \frac{\omega_1}{2}\right) - \frac{\omega_1}{2}\right\}t + B \sin\left\{\left(\omega - \frac{\omega_1}{2}\right) + \frac{\omega_1}{2}\right\}t$$

$$= \left(A \cos \frac{\omega_1}{2} t + B \sin \frac{\omega_1}{2} t\right) . \cos\left(\omega - \frac{\omega_1}{2}\right)t$$

$$+ \left(A \sin \frac{\omega_1}{2} t + B \cos \frac{\omega_1}{2} t\right) \sin\left(\omega - \frac{\omega_1}{2}\right)t$$

By adding vectorially we can condense these two terms into one involving

$$\sin\left\{\left(\omega - \frac{\omega_1}{2}\right)t + \phi\right\}$$

and expression becomes

$$\left\{\sqrt{\left(A \cos \frac{\omega_1}{2} t + B \sin \frac{\omega_1}{2} t\right)^2 + \left(A \sin \frac{\omega_1}{2} t + B \cos \frac{\omega_1}{2} t\right)^2}\right\} \sin\left\{\left(\omega - \frac{\omega_1}{2}\right)t + \phi\right\}$$

$$= \left\{\sqrt{A^2 + B^2 + 2AB \sin \omega_1 t}\right\} \sin\left\{\left(\omega - \frac{\omega_1}{2}\right)t + \phi\right\}$$

Now,

$$B + A \sin \omega_1 t = \sqrt{A^2 \sin^2 \omega_1 t + B^2 + 2AB \sin \omega_1 t}$$

and if B is large compared with A we can neglect terms in A^2 and we may say

$$\sqrt{A^2 + B^2 + 2AB \sin \omega_1 t} = B + A \sin \omega_1 t$$

to a close approximation.

Hence the expression for the resultant wave becomes

$$(B + A \sin \omega_1 t) \sin\left\{\left(\omega - \frac{\omega_1}{2}\right)t + \phi\right\} \qquad (2)$$

It will be seen that both expressions (1) and (2) represent the same amplitudes and modulation envelopes and therefore equivalent effects on a receiver. (1) however is derived from two waves each of amplitude $A/2$ representing a power proportional to $2(A/2)^2 = A^2/2$, while (2) is derived from one wave of amplitude A and power proportional to A^2. Thus when a strong enough homodyne is used the same effect is produced at the receiver by a two-side-band transmission using half the power which would be necessary with a single-side-band transmission.

Description of a Valve Wavemeter with a Range of 10 metres to 20,000 metres

(30,000 kilocycles to 15 kilocycles per second).

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Of the National Physical Laboratory.*)

Summary.

THE paper describes a valve oscillator wavemeter, which is an improvement on the previous design described in the *Wireless World*, 6th October, 1926. The operating range of wavelengths has been considerably extended and a separate valve modulator has been incorporated in the instrument. The frequency calibration is constant to about one part in a thousand over a wide range of variation of anode and filament voltage, and is not affected to more than one part in a thousand by changing the valve for another of the same type. This accuracy is considered sufficient to make the oscillator a valuable instrument in connection with many radio measurements.

Description.

1. The oscillator wavemeter has the following characteristics :—

(*a*) Wide range of operation (10 metres to 20,000 metres) obtained by means of separate coils, without any other change in the circuit.

(*b*) Continuous waves modulated at an audible frequency can be generated if desired over the whole range of operation. This is a very useful feature in connection with the tuning and testing of receiving circuits.

(*c*) Constancy of calibration (to one part in a thousand) with respect to changes in anode and filament voltage and changes of the valve.

(*d*) Portability. The batteries required are incorporated in the case of the instrument.

2. The circuit is shown in Fig. 1. The details of the components are as follows :—

A. *Coils.*—Three-plug centre-tapped coils are used. The construction of the coils calls for no special feature beyond the centre tapping and sufficient robustness of framework to ensure constancy of form. Low self-capacity is a desirable feature but the resistance does not seem to be a matter of great importance, except at the very short wavelengths. A pattern which has been

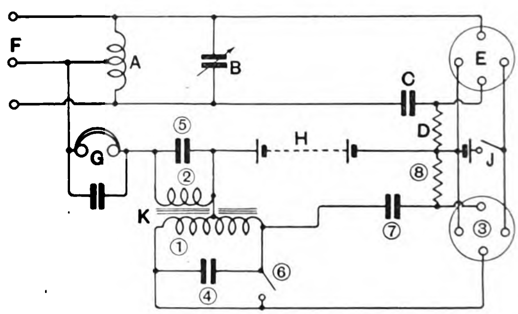


Fig. 1.

found suitable for the lower wavelength range (10-100 metres) is illustrated in the photograph. For the shortest wavelengths (down to 10 metres) the coil consists of two turns of about 7 cm. diameter of bare No. 18 tinned copper wire.

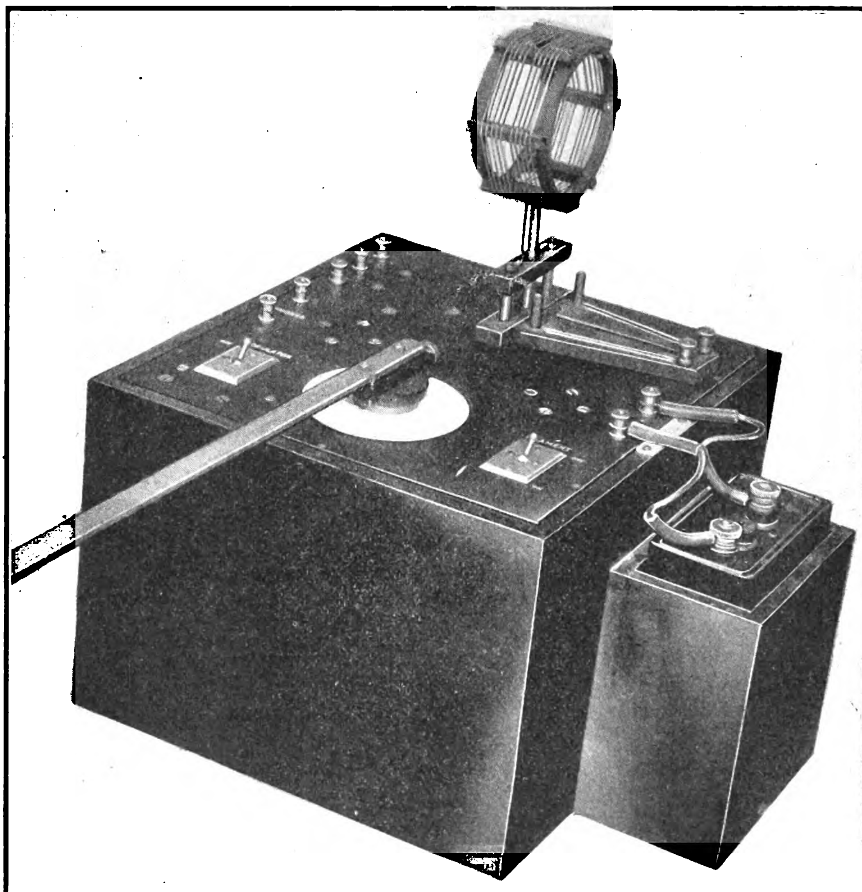
B. *Tuning Condenser.*—In the existing model the tuning condenser is a " low loss " 500$\mu\mu$F straight line capacity condenser. The square law pattern can be used with advantage unless it is desired to extend the range of each coil by means of an additional small fixed condenser. The principal requirement is low power factor and rigid construction. A remote control handle and a vernier drive are very desirable. It has been found that this is a simpler method of reducing

body capacity effects than any arrangement of screening, to which the circuit is not very well adapted.

C. *Small Coupling Capacity.*—This is a small air or mica dielectric condenser having a capacity of about 30-50$\mu\mu$F. In the existing model it consists of two brass discs about 4 cms. in diameter, the distance between which can be varied and then fixed. The chief requirement is that the capacity shall be variable up to about 100$\mu\mu$F or so, with a rigid locking arrangement. When the instrument has been assembled this capacity is adjusted to the smallest value consistent with oscillation over the whole range required, and is then fixed.

D. *Grid-Leak.*—A grid-leak of the metallic film vacuum pattern should be used, as this is likely to be more constant than the carbon filament type, and will have a smaller self-capacity. Its resistance should not exceed about 1 megohm, or else the oscillations may suffer from intermittent interruption, or "squegging."

E. *Valve.*—A valve of the short-path low impedance pattern has been used, as this appears to facilitate oscillation at the extreme low wavelengths. If the very short wave-length range is not required any ordinary dull emitter valve can be used.



General view of the complete wavemeter

F. *Coupling Terminals.*—These have been added to enable any suitable three terminal coil to be driven by the set, and also to permit of capacity coupling to any other circuit. It must be remembered, however, that any form of coupling to another circuit

will necessarily affect the calibration to some extent.

G. *Telephone Terminals.*—These are inserted in the high tension supply lead, and are shunted by a fixed mica condenser of about 0.001μF capacity. If preferred, a telephone transformer can be inserted at this point instead. The insertion of telephones does not affect the calibration within the limits stated.

H. *High Tension Battery.*—Four 15-volt dry battery units are used, and are housed in the base of the case. Forty to fifty volts would be sufficient, but it is well to have a margin for the deterioration of the cells. A by-pass condenser of about 1μF (paper) is desirable if dry cells are used.

I. *Low Tension Battery.*—A 2-volt accumulator is housed in the case attached to the side of the main box. It is better not to have an accumulator contained in the box itself, as this might increase the humidity of the interior of the box and lower the insulation resistances.

K. *Modulating System.*—Essentially this consists of a low frequency oscillating circuit driven by a separate valve with the same batteries, and coupled magnetically to the high frequency circuit so that a small low frequency E.M.F. is added to the anode voltage of the high frequency circuit.

The low frequency oscillating circuit was made by rewinding an ordinary intervalve low frequency transformer with two windings—one (1) of about 4,000 turns, approximately centre tapped, and one (2) of about 100 turns, or preferably of say 200 turns tapped at 50 and 100, so that the best output winding can be chosen from 50, 100, 150 and 200 turns. The low frequency oscillations are tuned to any desired note by means of a fixed condenser (paper dielectric will do for this) of capacity 0.01 to 0.02μF. It may be necessary to shunt the output winding with a fixed condenser (5) (about 0.001μF) to prevent any radio frequency choke effect. A short circuiting switch across the modulator main winding enables the modulator to be put in or out of action as required.

The grid coupling condenser (7) is about 0.005μF and the grid-leak (8) about 1 megohm.

3. Action of the Circuit and Constancy of Calibration.

The circuit will be recognised as a variation of the well-known Hartley circuit. Its special suitability for the present purpose appears to lie in the fact that the oscillations are accompanied by rectification in the grid circuit, producing a considerable fall of mean grid potential and correspondingly low anode current. This has the effect of restricting the amplitude of the oscillations generated. The grid coupling capacity is reduced to as low a value as possible for the same purpose. Under these conditions the frequency of the oscillations is very little affected by changes in the supply voltage. The circuit seems to be quite remarkable in this respect. A very thorough test of the constancy of the calibration was carried out, and showed that over the whole range of frequency covered by the wavemeter a variation of from 30 to 70 volts in the high tension supply and of from 1.5 to 2 volts in the filament voltage affected the frequency calibration to less than one part in a thousand. Changing the valve for another of the same pattern, picked at random, also did not affect the calibration to one part in a thousand. The important practical consideration is that the changes of anode and filament voltage likely to occur in practice will not cause any appreciable change in the frequency of the oscillations.

The incorporated separate valve modulator has proved to be a very useful feature. It does not affect the mean radio frequency and greatly facilitates the adjustment and testing of receiving apparatus. Compared with the grid-leak interrupter arrangement adopted for the previous design, it is certainly not so simple and requires more auxiliary apparatus. On the other hand it has the advantage of greater certainty and uniformity in action, with a much less disturbing effect on the mean frequency and general character of the radiation.

[This work was carried out for the Radio Research Board and is published by permission of the Department of Scientific and Industrial Research.]

The Suppression of Parasitic Oscillations in Valve Circuits.

By M. Reed, M.Sc., A.C.G.I., D.I.C.

Summary.

THIS article considers the conditions that must be satisfied for oscillations to be maintained in the case of a "tuned-anode," a "tuned-grid," and a Hartley oscillator, respectively.

Methods are given that can be used to stop an oscillation in any one of the above cases.

The treatment is quite general; no attempt being made to apply the methods to any particular detector, amplifier, or oscillator that may be encountered in radio practice.

Introduction.

Parasitic oscillations are of great importance in radio engineering. They form a constant source of trouble in all types of receiving and transmitting apparatus.

In receiving sets they lower the efficiency of reception owing to the "howling" which sometimes arises from their presence, and also to the energy which they absorb.

In transmitting apparatus the parasitic oscillations may sometimes be sufficiently strong to prevent the propagation of the legitimate oscillation. In any case they will spoil the wave-form of the oscillation propagated, and in addition they will lower the efficiency of the oscillator, since their presence will result in the absorption of power which would normally go to the maintenance of the legitimate oscillation.

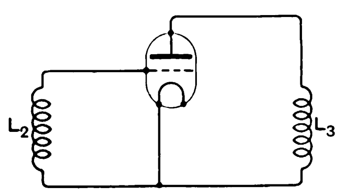


Fig. 1.

Undesirable oscillations cannot always be wholly eliminated by the careful design of the apparatus, because they are generally confined to circuits which have as one of their components the stray capacity which may exist between the electrodes of the valve, between coils, or between other parts of the apparatus. These stray capacities, in addition to forming a component for the parasitic oscillatory circuit, are generally such that they form the electrostatic coupling necessary for the maintenance of the oscillation.

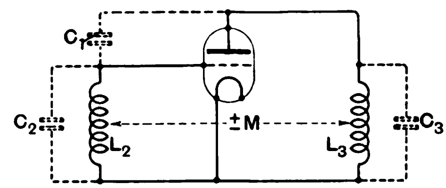


Fig. 2.

In some cases electromagnetic coupling is provided owing to the proximity of coils, transformer windings, or similar components.

Where a common H.T. battery is used for a number of valves, it is possible for this battery to act as a resistance coupling.

To eliminate undesirable oscillations completely in any given piece of apparatus, it is not sufficient always to rely solely on careful design. In any case it would not be very convenient to redesign and rebuild the apparatus continually until parasitic oscillations are completely eliminated.

It is therefore essential that these oscillations should be eliminated by some simple alteration in the apparatus, such as the addition of a suitable resistance or condenser.

The Possible Parasitic Oscillatory Circuits.

Fig. 1 shows a simple circuit consisting of an anode and grid coil. Now it is possible for both the coils L_3 and L_2 to have self capacity, and also that there should be stray magnetic and electrostatic coupling between the grid and anode circuits.

Fig. 2 shows Fig. 1 redrawn with these quantities taken into account.

From Fig. 2 it is seen that there are three possible oscillatory circuits; they are :—

1. The Hartley circuit, comprising C_1, L_2, and L_3.
2. The anode circuit, comprising L_3 and C_3.
3. The grid circuit, comprising L_2 and C_2.

Each of these circuits will now be considered in detail.

The Hartley Circuit.

The Hartley circuit is shown in Fig. 3. It is made up of C_1, L_2 and L_3. The self-capacities of L_2 and L_3 have been neglected for the moment.

For this circuit to be maintained in oscillation, the following expression must be satisfied :—

$$C_1RR_a(L_3+L_2\pm 2M)<(L_3\pm M)[m(L_2\pm M)-(L_1\pm M)]^*$$

where R=resistance of the oscillatory circuit;

R_a=internal resistance of the valve;

m=amplification factor of the valve.

The maintenance of this oscillation does not depend on the sign of the mutual induction so long as it has not got a negative value

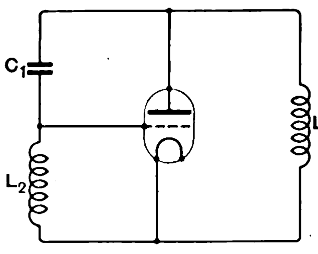


Fig. 3.

which is equal to or greater than the inductance of either the grid or the anode coil. If the mutual inductance has a greater negative value, then the condition for the maintenance of the oscillation, namely, that the grid and anode voltages should be 180 degrees out of phase, will be impossible.

To prevent the Hartley circuit from oscillating, the following methods can be employed :—

1. From the formula it is seen that for a given valve and a given L_2, L_3 and M, the oscillation can be prevented by increasing C_1, R, or their product. It is usually found most convenient to increase the product. Fig. 4 shows how the resistance and capacity of the Hartley circuit can be increased. C is a condenser placed across the grid and anode terminals and R_2 is a non-inductive resistance connected in the grid circuit.

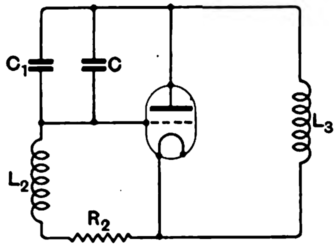


Fig. 4.

In the case of oscillators it can be seen that R_2 will not interfere with a normal oscillation existing in the anode or the grid circuit. C must be so chosen that the normal oscillation is not affected.

If the legitimate oscillation is of low frequency then there will be no difficulty in stopping an undesirable oscillation in the Hartley circuit.

Example.

An anode-tuned oscillator had the following dimensions :—

Tuning capacity=0.0567μF.

L_3=0.48 henries.

L_2=0.08 ,,

Frequency of anode circuit=965 cycles/sec.

C_1=90$\mu\mu$F.

Frequency of Hartley oscillation=40,000 cycles/sec.

It was found that if

$$C = 1{,}530\mu\mu\text{F}$$

and $$R_2 = 10{,}000 \text{ ohms},$$

the Hartley oscillation was completely stopped.

If the legitimate oscillation is of high frequency, then it will be found that C must be made very small and R_2 must be increased so as to obtain the necessary product.

* Van der Bijl. *Thermionic Vacuum Tube*, p. 283.

2. From Fig. 5 it is seen that if L_2C_R was tuned to the frequency of the Hartley oscillation it would act as a rejector circuit to that oscillation (indicated by the arrow).

Under these conditions the circuit L_2C_R would offer a very high impedance to the Hartley oscillation, and it would make it impossible for that oscillation to persist.

A similar condition could be obtained by connecting a suitable condenser across L_3.

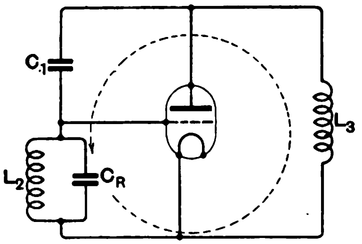


Fig. 5.

Thus the Hartley oscillation can be prevented by connecting a suitable condenser across the anode or grid coil. This method can be used so long as the grid (or anode) circuit does not tend to oscillate because of the added capacity.

In the case of oscillators the condenser must be connected across the coil which does not form part of the normal oscillatory circuit.

The Grid Circuit.

This circuit consists of L_2 and C_2 (see Fig. 2).

There are two cases to be considered here :—

(*a*) When the natural frequency of the grid circuit is less than that of the anode circuit;

(*b*) When the natural frequency of the grid circuit is greater.

Case (*a*).

Here we are, in effect, dealing with a simple "tuned-grid" oscillator. For such an oscillation, if the coupling is magnetic, it is well known that the sign of the mutual induction must be negative.*

One of two methods can be employed to prevent the oscillation :—

1. In Fig. 6 is shown a vector diagram for a "tuned-grid" oscillator with electrostatic coupling. To obtain this diagram it is assumed there is a current I_2 in the grid coil, and that the coupling is provided by the condenser C. It is assumed that there is no magnetic coupling between the anode and grid coils. This assumption is used only for the purpose of drawing the vector diagram. Further on the effect of the magnetic coupling is considered.

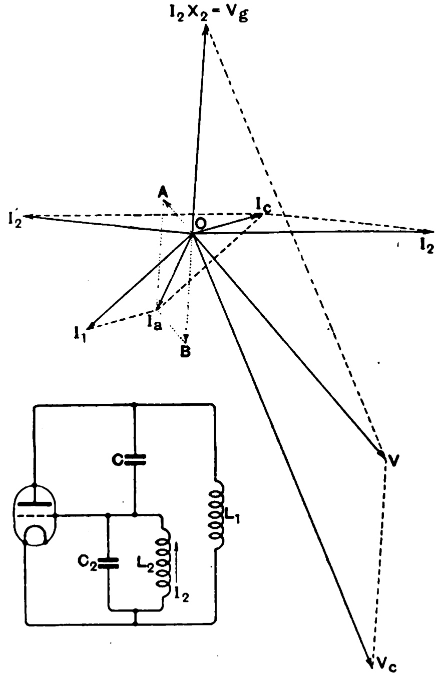


Fig. 6.

The symbols employed are as follows :—

OI_2=current in grid coil$=I_2$.

OI_2X_2=E.M.F. induced in the grid coil$=-V_g$.

OI_2'=current through C_2
$=-V_g\times j\omega C_2=-j\omega C_2V_g$.

OI_c=current through C $=OI_2+I_2'O$.

OV_c=resulting voltage across C
$=-jI_c/\omega C$.

OV=voltage across L_1
$=OV_c-V_g=-V_a$.

$OA=V_a/R_a$.

$OB=gV_g$.

OI_a=anode current $=OA+OB=I_a$.

OI_1=current through $L_1=OI_a-OI_c$.

* Turner's *Outline of Wireless*, p. 125.

The condition that must be satisfied in this vector diagram is that the angle I_1OV must not be greater than 90 degrees, *i.e.*, the current through L_1 must not lag by more than 90 degrees on the voltage OV.

This condition can only be satisfied if OV_c is longer than OI_2X_2, *i.e.*, if the voltage across C is greater than the voltage across C_2. If this is not the case it will be found impossible to construct the vector diagram, which means that it will not be possible for an oscillation to be maintained in the grid circuit. Thus to prevent an oscillation in this circuit we must reduce the voltage across the condenser C, *i.e.*, the value of the capacity of this condenser must be increased.

If in addition to the electrostatic coupling there is also a magnetic coupling, then we have the following conditions. Under normal circumstances the electrostatic coupling will help the magnetic coupling to maintain the oscillation, since the capacity between the anode and the grid is generally not sufficient to make OV_c less than V_g (see Fig. 6). If this capacity is increased, then as OV_c becomes less than V_g, the capacity coupling will tend to neutralise the magnetic coupling until finally it will become impossible for the valve to maintain the oscillation any longer.

When using this method to stop a parasitic oscillation in the grid circuit, a suitable resistance must be inserted in the Hartley circuit, if that circuit tends to oscillate. In all the methods which follow, it is tacitly assumed that this precaution is taken if the Hartley circuit tends to oscillate.

The anode circuit cannot oscillate as the mutual induction is of the wrong sign, since the natural frequency of the anode circuit is above that of the grid circuit (see Appendix 1). In any case the condenser across the anode and grid will prevent the anode circuit from oscillating (see below).

(2) Another method that can be used to prevent an oscillation in the grid circuit is to connect across the anode coil a condenser of such a value that the natural frequency of the anode circuit is now less than that of the grid circuit. In this case the grid circuit will not be able to oscillate because the mutual induction will be of the wrong sign, this case demanding that the sign of the mutual induction should be positive. (This follows from the corresponding case of the anode circuit which is considered in Appendix 1.)

This method can only be used if the anode circuit itself does not tend to oscillate.

If the coupling is electrostatic, then the method (1) is the only one which can be employed.

Case (*b*).

In this case if the coupling is magnetic, the sign of the mutual induction must be positive. This corresponds to the anode circuit case given in Appendix 1.

Three methods can be employed:—

1. Connect a condenser across the anode and the grid in the manner indicated on page 2. Here again the anode circuit cannot oscillate because the mutual induction is of the wrong sign.

2. Connect a condenser across the anode coil, thus decreasing the natural frequency of the anode circuit, and make this condenser of such a value that the mutual induction will not be large enough to maintain the oscillation in the grid circuit.

The reason for this will be seen from Appendix 2, where the corresponding case for the anode circuit is considered.

3. Connect a condenser across the grid coil so that the natural frequency of the grid circuit is now less than that of the anode circuit, thus making the mutual induction of the wrong sign for the maintenance of the oscillation.

As before, this method can only be used if the anode coil does not tend to oscillate.

For electrostatic coupling, or combined electrostatic and magnetic coupling, see the remarks below.

The Anode Circuit.

This circuit consists of L_3 and C_3 (see Fig. 2).

As in the case of the grid circuit, there are two cases to be considered.

Case (*a*) *When the N.F. of the Anode Circuit* $<$ *N.F. of Grid Circuit.*

In this case we have, in effect, a simple "tuned-anode" oscillator.

For magnetic coupling, the sign of the mutual induction must be negative (see Appendix 1).

Two methods can be employed to stop an oscillation in this circuit:—

1. By connecting a suitable condenser across the anode and grid. The vector

diagram in Fig. 7 shows that this case is similar to the one considered for the grid circuit.

OI_1'=current through $C_1=j\omega C_1\times OV$.

$OP=OI_2+OI_1'$.

OI_1=current through $L=I_a—OP$.

As before, the condition to be satisfied is that OI_1 must not lag more than 90 degrees on OV. This condition can only be satisfied if OV_c is greater than V_g, and hence the anode circuit can be prevented from oscillating by having a suitable value for C.

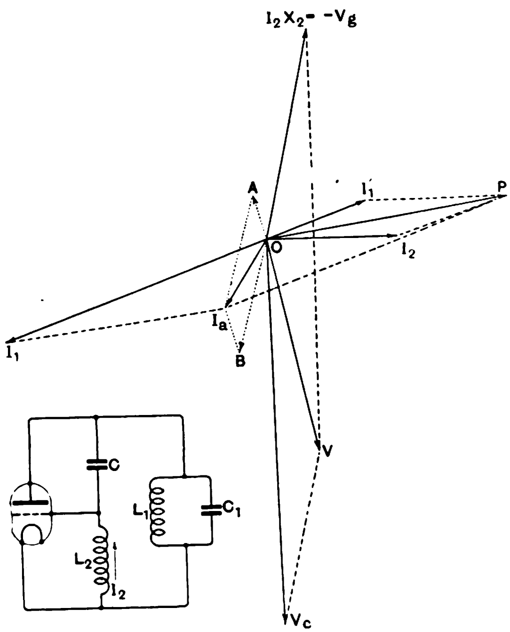


Fig. 7.

2. Connect a condenser across the grid coil so that the frequency of the anode circuit is now greater than that of the grid circuit. The sign of the mutual induction will then prevent the anode circuit from oscillating. This method can only be used if the grid circuit does not intend to oscillate.

Case (b) N.F. of Anode Circuit > N.F. of Grid Circuit.

In this case, if the coupling is magnetic, the sign of the mutual induction must be positive (see Appendix 1).

Three methods can be used to stop the oscillation :—

1. Connect a suitable condenser across the anode and grid. The electrostatic coupling thus obtained neutralises the magnetic coupling (see below).

2. Connect a condenser across the grid coil, thus reducing the natural frequency of the grid circuit so that the value of the mutual induction becomes insufficient to maintain the anode circuit in oscillation. The reason for this is given in Appendix 2, where it is shown that when the natural frequency of the anode circuit is greater than that of the grid circuit, the value of the mutual induction required is greater when the difference between these two frequencies is increased.

In this method the grid circuit cannot oscillate because the sign of the mutual induction is positive.

3. Connect a condenser across the anode coil so that the frequency of the anode circuit becomes less than that of the grid circuit. It will then be impossible for the anode circuit to oscillate since the mutual induction is positive.

This method can only be used if the grid circuit does not tend to oscillate.

If in Case (*a*) the coupling is electrostatic, then only method (1) can be used. For combined coupling the remarks made for the corresponding case in connection with the grid circuit apply equally well here.

Case (b) with Electrostatic or Combined Coupling.

For the sake of clearness the grid circuit oscillations are considered.

In Case (*b*) if the coupling is solely electrostatic it will be impossible for an oscillation to be maintained in the grid circuit. The reason for this is as follows :—

If the grid circuit oscillates at a frequency which is above the natural frequency of the anode circuit, then at that frequency the reactance of the anode circuit will be positive. That is, the current through the anode circuit must lead on the applied voltage. From Fig. 6 it is seen that if the grid circuit oscillates, it is impossible for the current through the anode circuit to lead on the applied voltage V. Thus it is impossible

for the grid circuit to oscillate if the frequency of the oscillation is above the natural frequency of the anode circuit and the coupling is solely electrostatic.

It is probable that if the coupling is sufficient, the anode circuit will oscillate, *i.e.*, with electrostatic coupling the circuit which has the lower natural frequency can only oscillate.

If the coupling is both electrostatic and magnetic then it is only possible for the grid circuit to oscillate if the latter is the greater. The electrostatic coupling tends to neutralise the magnetic coupling, and hence in this case a smaller capacity will be required to stop the grid circuit from oscillating than in the corresponding example of Case (*a*).

The above remarks apply equally well for corresponding case in connection with oscillations in the anode circuit.

Conclusions.

When applying the methods given in this article to particular cases, care must be taken that the added capacities do not prevent the proper functioning of the apparatus in question. The choice of the method to be employed will be governed by this consideration.

The methods given can be applied most efficiently to "tuned-anode" or "tuned-grid" oscillators giving an oscillation at audio-frequency. In such cases the added capacities necessary to prevent an undesired oscillation will be too small to affect the normal oscillation.

For oscillators of higher frequency there is a danger that the added capacities will interfere with the legitimate oscillation, and where it is necessary to place a condenser across the anode and grid terminals, it is possible that the production of the proper oscillation may be prevented.

In the case of amplifiers when a condenser is placed across the anode and grid, care must be taken that it has not got a sufficiently high value to interfere with the amplifying efficiency of the valve.*

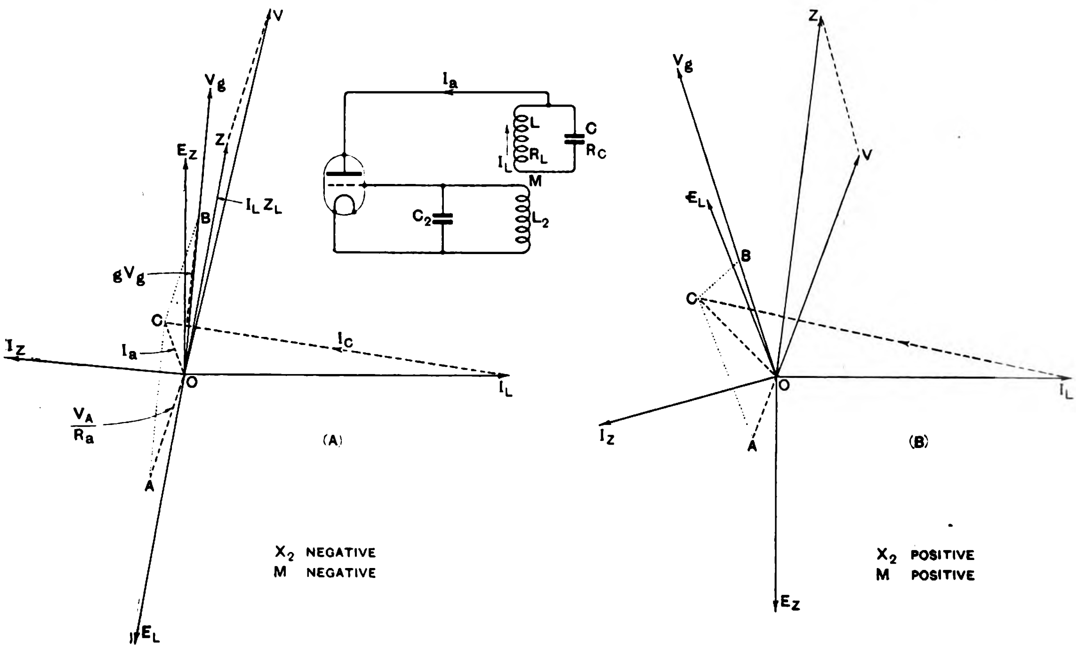


Fig. 8.

* See H. W. Nichols. *Physical Review*, June 1919.

SUMMARY OF THE METHODS USED IN THIS ARTICLE.

Oscillator.	Case.	Coupling possible.	Necessary sign of Mutual Induction.	Method employed to stop the Oscillation.	Remarks.
Hartley		Magnetic coupling may be present in addition to the permanent electrostatic coupling	Positive or negative	1. Insert suitable resistance, capacity, or both in the Hartley circuit	In the case of H.F. oscillators and amplifiers it is usually possible to insert resistance only
				2. Connect a suitable condenser across grid coil	Only possible if the grid or anode circuit does not tend to oscillate
Tuned Grid	N.F. of anode circuit above N.F. of grid circuit	1. Magnetic 2. Electrostatic	Negative	1. Connect a suitable condenser across the anode and grid	If necessary prevent the Hartley circuit from oscillating by adding suitable resistance
				2. Connect a suitable condenser across the anode coil	1. Can only be used in the case of magnetic coupling 2. Only possible if anode circuit does not tend to oscillate
	N.F. of anode circuit below N.F. of grid circuit	Magnetic	Positive	1. Connect suitable condenser across anode and grid	Prevent Hartley oscillation if necessary
				2. Connect a suitable condenser across anode coil	Prevent Hartley oscillation if necessary
				3. Connect a suitable condenser across grid coil	Only possible if the anode circuit does not tend to oscillate
Tuned Anode	N.F. of grid circuit above N.F. of anode circuit	1. Magnetic 2. Electrostatic	Negative	1. Connect a suitable condenser across anode and grid	Prevent Hartley oscillation if necessary
				2. Connect a suitable condenser across grid coil	1. Can only be used in the case of magnetic coupling. 2. Only possible if grid circuit does not tend to oscillate
	N.F. of grid circuit below N.F. of anode circuit	Magnetic	Positive	1. Connect a suitable condenser across anode and grid	Prevent Hartley oscillations if necessary
				2. Connect a suitable condenser across grid coil	Prevent Hartley oscillation if necessary
				3. Connect a suitable condenser across the anode coil	Only possible if the grid circuit does not tend to oscillate

N.F. = Natural frequency.

APPENDIX 1.

The "Tuned-Grid," "Tuned-Anode" Oscillator.

Generally, both the grid and anode coils have self-capacity. In this appendix, the condition for the anode circuit to oscillate under such circumstances will be determined.

The condition to be satisfied can be best determined by means of a vector diagram. To obtain this diagram, it is assumed that there is a current I_L in the anode coil, and that there is a mutual induction M between the anode and grid coils.

The capacity between the grid and the anode is neglected since it unnecessarily complicates the diagram.

The vector diagram is shown in Fig. 8.

OI_L=current in anode coil$=I_L$.
OE_2=E.M.F. induced in the grid coil $=-j\omega MI_L$.
OI_2=resulting current in the grid coil$=j\omega MI_L/Z_2$.
OV_g=grid voltage $=jI_2/\omega C_2=V_g$.
OE_L=E.M.F. induced into anode coil $=-j\omega MI_2$.
$OZ=I_LZ_L$.
OV=anode volts $=OZ-OE=-V_a$.
$OB=gV$..
$OA=V_a/R_a$.
OC=anode current$=OB+OA=I_a$.
CI_L=current through $C_1=I_L-I_a=OI_L-OC$.

In these vector diagrams the condition that must be satisfied is that the angle between CI_L and OV must be less than 90 degrees—that is, the current through the condenser C_1 must not lead by more than 90 degrees on the anode voltage. In Fig. 8 two vector diagrams are shown.*

In Case (*b*) it is assumed that the frequency of the anode circuit is above that of the grid circuit, *i.e.*, X_2, the reactance of the latter circuit, is positive. It is found that in this case it is only possible to make the angle between CI_L and OV less than 90 degrees, if the sign of the mutual is positive.

In Case (*a*) it is assumed that the frequency of the anode circuit is less than that of the grid circuit. From the vector diagram it is seen that in this case the sign of the mutual induction must be negative. The condition that must be satisfied for the simple "tuned-anode" oscillator.

We are interested in the Case (*b*). Thus it is seen that when the natural frequency of the anode circuit is above that of the grid circuit, it is possible for the former to oscillate only when the sign of the mutual induction is positive.

* These diagrams were given by Prof. C. L. Fortescue during the course of a lecture at the City and Guilds College, South Kensington.

APPENDIX 2.

In this appendix the effect of the difference between the values of the natural frequency of the anode and grid circuits on the value of the mutual induction required to maintain an oscillation in the anode circuit, is shown.

For a simple "tuned-anode" oscillator where the natural frequency of the grid coil is much above that of the anode circuit, the sign of the mutual induction necessary to maintain the oscillation is negative. As the frequency of the anode circuit is raised (by reducing the value of the anode capacity), *i.e.*, as the anode circuit is brought nearer to the natural frequency of the grid coil, the value of the mutual induction required is seen from the formula—

$$M=\frac{RR_aC}{m}-\frac{L}{m}\ *$$

to be reduced. If the capacity of the oscillatory circuit is still further reduced so that the natural frequency of the grid coil is now less than that of the anode circuit, the sign of the mutual induction required to maintain the oscillation is now positive (see above). Further reduction of the capacity must therefore require an increased value for the mutual induction in order that the expression $M=f(C)$ may be continuous. [$f(C)$ denotes "function C."]

Hence when the natural frequency of the grid coil is below that of the anode circuit, the lower the frequency of the latter the less the value of the mutual induction required to maintain that circuit in oscillation.

* In the above formula—

M=Mutual induction between the anode and grid circuits.
R=Resistance of the anode circuit.
C=Capacity of the anode circuit.
L=Inductance of the anode circuit.
R_a=Resistance of the valve.
m=Amplification factor of the valve.

The expression gives the condition necessary for a "tuned-anode" oscillator to be just about to oscillate.

Van der Bijl. *Thermionic Vacuum Tube*, p. 275.

A Graphical Method of Amplifier Coupling Design.

By Marcus G. Scroggie, B.Sc.

(*Research Department, Burndept Ltd.*)

In considering the correct coupling condenser and grid-leak to use in order to meet any given conditions in a resistance or choke coupled amplifier Fig. 1(*a*), the accompanying graph is probably the most useful form in which to present the quantities

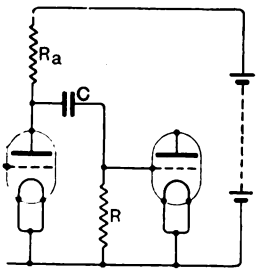


Fig. 1(*a*).

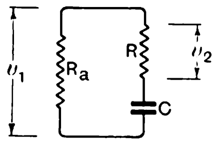


Fig. 1(*b*).

in question. There are three main points to bear in mind :—

(1) The drop in amplification due to the impedance of the condenser as compared with that of the leak.

(2) The drop in amplification due to the shunting effect of the leak.

(3) The time constant of discharge of the condenser.

(1) is important at the lowest frequencies, while (2) need not be considered at low frequencies, nor at any frequency provided that the leak resistance is large compared with the anode resistance; (3) should not enter into the matter at all were one to keep strictly within the limits of the amplifier, so that the greatest peak voltage of signal or atmospheric never makes the grid positive. In practice such is seldom the case as the output would then be surprisingly low; a few peaks do occasionally overstep the normal limits and produce momentary grid current, and if the charge on the coupling condenser can leak off very rapidly the quality of reproduction suffers only slightly. The time constant of the condenser-leak combination should, then, be as low as possible consistent with (1).

The proportion of signal E.M.F. across the anode resistance (or choke) which is applied to the next grid is, say, p :—

$$p = \frac{v_2}{v_1} = \frac{R}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}}$$

where R is the resistance of the grid-leak,
C is the capacity of the coupling condenser,
ω is $2\pi \times$ frequency. (See Fig. 1 (*b*).)

so
$$p = \frac{\omega RC}{\sqrt{\omega^2 C^2 R^2 + 1}}$$

but $CR = T$, the time constant, which is the

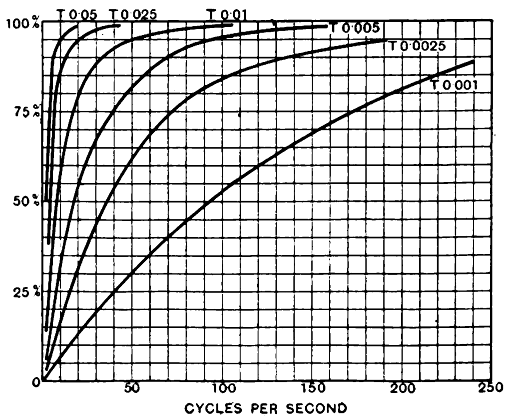


Fig. 2.

time in seconds for the condenser to discharge through R to about 36 per cent. of its original potential, so

$$p = \frac{\omega T}{\sqrt{\omega^2 T^2 + 1}}$$

It is clear that T can be made up of C

and R in any proportion without affecting p, so all that is required is to decide on how small p can be made for some frequency, and read T off from the curve-sheet, Fig. 2, R cannot be made small without conflicting with (2) nor must it be made very large, or the shunting capacity of the grid circuit of the valve, which may be quite large with high magnification valves, will take charge. About 0.5—5 megohms covers most cases; then dividing T by R in megohms gives C in microfarads.

It is extremely doubtful whether even a trained ear can detect less than a 30 per cent. drop in strength of any restricted band of frequencies when mixed with others, and as 32 cycles may be said to constitute the lower limit, a value of T which may be considered satisfactory for a single stage, with the best loud-speakers available, is 0.005, say a 1 megohm leak and an 0.005 microfarad condenser. With two stages of amplification the values of p are, of course, squared, making it necessary to increase T.

The curves give a very clear picture of what is happening to the lower frequencies, and enable one to judge the cut-off effect of any particular coupling without difficulty.

Radio Patent Litigation in America.

By A. H. Morse, A.M.I.E.E., Mem.I.R.E.

ALTHOUGH American patent law was founded on the British, there is now a wide difference between them; and it is characteristic of this difference that it militates against the stability of American trade. The radio trade has furnished a number of proofs of this contention; and the latest is of particular interest.

In the evolution of broadcasting one of the most important factors was the application to valve circuits of the principle of regeneration. In England, this application was patented to C. S. Franklin in 1913; and E. H. Armstrong successfully applied for an American patent on the same invention in the same year. In 1924, however, the U.S. patent office issued another patent on this invention to Lee de Forest, who successfully claimed 6th August, 1912, as his date "of conception." The Armstrong interests have naturally availed themselves of recourse to the Courts in an endeavour to maintain their position; but now it is reported that they will fight no more. In view of the fact that for years the Armstrong invention was used in almost every radio receiver made in America, and that enormous sums were paid in royalties therefor, it will be seen that a very complicated situation has now arisen; and the complications are so numerous and involved, that the parties most interested can hardly know where they stand.

Had the Armstrong patent stood, "regeneration" would have come into the "public domain" in America in October, 1931; whereas, in the ordinary course, the proprietors of the De Forest patent will now have a legal monopoly of regeneration until September, 1941. By virtue of the patent-pooling agreement which is the basis of the Radio Corporation of America, that Corporation seems unlikely to be seriously affected by the changed situation; in fact, it may derive great benefit from the ten years' extension of its monopoly of regeneration. On the other hand, it may find itself confronted in all its fields of activity by a competitor very much strengthened by the ascendancy of De Forest over Armstrong; for at the aforesaid "date of conception" De Forest was in the employ of the Federal Telegraph Company of California, who, therefore, under a provision of American patent law, have what are known as "shop rights" to the invention in question. As is well-known, the Federal Co. has been the Radio Corporation's greatest competitor; and it has recently conveyed to the Mackay cable interests all its rights in the communication field.

In the circumstances, one can only speculate on all the results of the changed situation; but one may be certain that it will lead to much litigation over those royalties which may now be claimed to have been paid to the wrong party. And it is just as well, perhaps, for the British radio trade that there *are* differences between patent law and practice in Britain and America.

Wave Propagation and the Weather.

By F. Charman.

IN the issue of *E.W. & W.E.* for December, 1925, Mr. S. K. Lewer showed how some very interesting research in wave-propagation may be carried out with the aid of a simple receiver only, and reproduced some very interesting curves which are the outcome of his work. For some considerable time the writer carried out some similar experiments, not, however, with the object of determining the causes of seasonal variations in the signal strength of distant stations, but in an endeavour to trace some relation between the daily variations superimposed on the seasonal changes and the meteorological conditions at the receiver. In this article a description will be given of the methods employed, followed by an account of the results obtained, and finally, some attempt will be made to explain the phenomena observed.

The obvious line of attack is to obtain a station at some large distance from the receiver, and to plot daily the field strength at the receiver alongside the barometric changes, noting as we proceed any peculiarities of the weather. Now, provided we have a good receiver, say an efficient detector followed by one stage of note-magnification, or a superheterodyne, it is fairly easy to "obtain" a station "A" at a large distance, and it is possible with a little care to plot the field strength coefficient to within an accuracy of about 10 per cent., but on the following day, when we go to take observations on station "A," it will perhaps not be working, and in its place we shall have another station in some more or less remote part of the globe, and radiating different energy. Now this state of affairs is not easily overcome, the only apparent means of escape being to arrange a schedule with the operator at the other end, which will be seen to be difficult when it is considered that the tests are likely to extend over years and daily figures are required.

The writer, therefore, before embarking on the tests proper, made a survey of the ether lasting over two to three months, in order to find out which part of the globe was most likely to provide a station whose daily appearance on the ether was a high probability, and finally evolved a scheme whereby the observations could be made on any one of a collection of stations and the results reduced to one of them. This overcame the difficulty mentioned above. It was found that the amateurs of New Zealand were the most reliable, particularly one, Z2AC, but even in this case it was seldom possible to hear the same station daily over any long period. It would appear on first consideration that the U.S.A. would offer the best possibilities, but an examination of the log showed that the American stations were very irregular in their appearance. It was decided to plot the more commonly heard New Zealand stations, and also to plot a curve of the average audibility of the U.S.A., obtained from the whole log daily.

During the year in which the experiments to be described were made great increase was made in the use of the shorter wavelengths, and now it would be only necessary, for the purpose of the experiments described here, to pick on a steady commercial station, many of which are now working continually on short waves.

The tests have so far been limited to the band of wavelengths, between 30 and 45 metres, as it was decided to deal with other wavelengths after something had been found of this one band. Reception has been carried out at the time of maximum audibility on the band, about two hours after sunrise, care being taken to avoid the sudden dip in strength which was found to occur every day in connection with sunrise. Thus the time of reception varies with the season, being about 06.00 G.M.T. in the summer, and falling to 08.30 in the winter.

The signal strengths noted were plotted in the well-known "R" code, against time, the barometric pressure being plotted alongside for comparison, and the whole operation repeated daily. The "R" code is very convenient for this purpose, since,

being a logarithmic function of the field strength, it is capable of embracing wide limits within a small space.

The receiver employed consisted of an oscillating detector valve followed by one stage of low-frequency amplification, the collector being a small aerial, loosely coupled to the receiver. As a check on the receiver and on the operator's ear, a standard signal was measured daily, this being induced locally into the aerial system. The measurement was performed by means of the usual shunt resistance method. A fixed resistance was inserted in the anode circuit of the amplifier, and the telephones were tapped across this resistance. This method has several disadvantages, the chief being the difficulty in keeping a constant impedance in the anode circuit, but as great accuracy is not called for in these experiments, it was chosen as being most convenient.

Fig. 1 shows the result of the first three months' work. In this section 4 is the actual graph obtained for Station Z2AC, whilst sections 1, 2 and 3 cover other stations in New Zealand and Australia. Section 7 is a rough graph, plotted from the general appearance of the logbook, for east coast stations in districts 1, 2 and 3 of U.S.A. Section 6 shows the barometric variations, and section 8 represents the limiting effect of static upon reception. The static has been plotted with respect to other characteristics than its strength alone, and so, for example, static of strength R^4 would be plotted as R^2 or R^3 if it were only intermittent, but as R^5 if it were continual. In general, when an R^4 signal is the weakest that can be easily read through the static, the static is plotted as R^4. In section 5 a graph has been plotted to represent New Zealand. It was noticed that certain New Zealand stations, in particular Z2XA, always bore a constant signal strength ratio to Z2AC, and by comparing these other stations, the audibility curve for Z2AC has been filled in for dates when this station itself was not heard, and by carrying out this principle throughout the whole period of the tests, a very complete curve for New Zealand has been obtained. This method is, of course, only applicable to a number of stations located within a small area, and it would not do to build

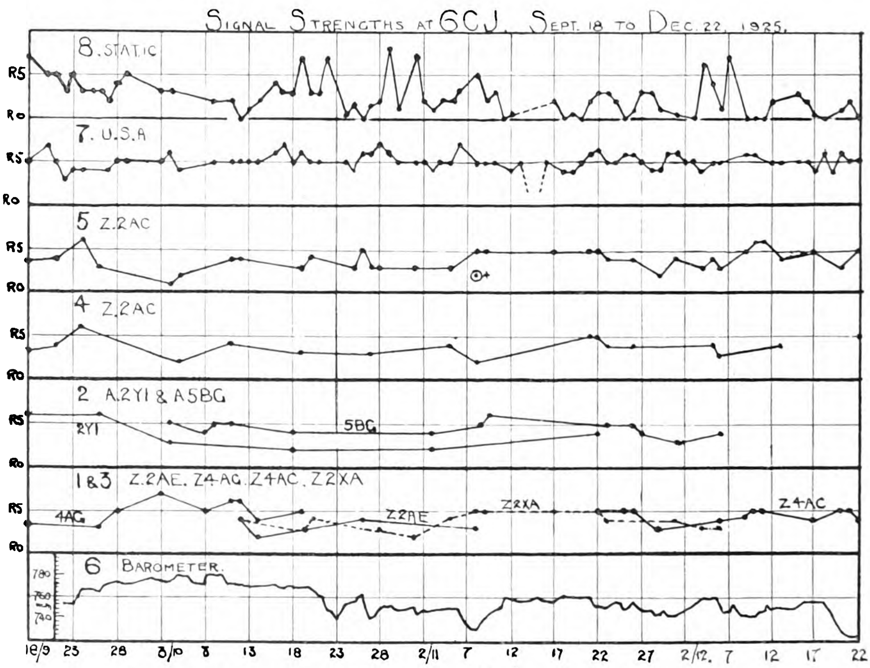


Fig. 1. *Curves obtained for the first three months.*

up a curve for Z2AC with the help of another station in, say, Brazil. It has been ascertained that the key station, Z2AC, has not altered its radiated power to any appreciable extent during the time of the measurements.

Fig. 2 shows a set of graphs completing a period of ten months, from September, 1925, to June, 1926. Australia has been plotted separately where possible, as it was noticed that signals from there differed from those coming from New Zealand. It was observed that signals from Brazil behaved in the same manner as those from New Zealand, but observations on Brazilian stations were not sufficiently numerous to allow of a good graph being plotted. The point is mentioned, however, as interesting in connection with certain indications having been obtained that the effect of the weather is selective with regard to direction.

The graphs thus obtained were very instructive, not because they yielded any very definite results but because they indicated definite lines upon which to work, which have been followed up by the writer in the later periods of the tests. However, let us look at the graphs.

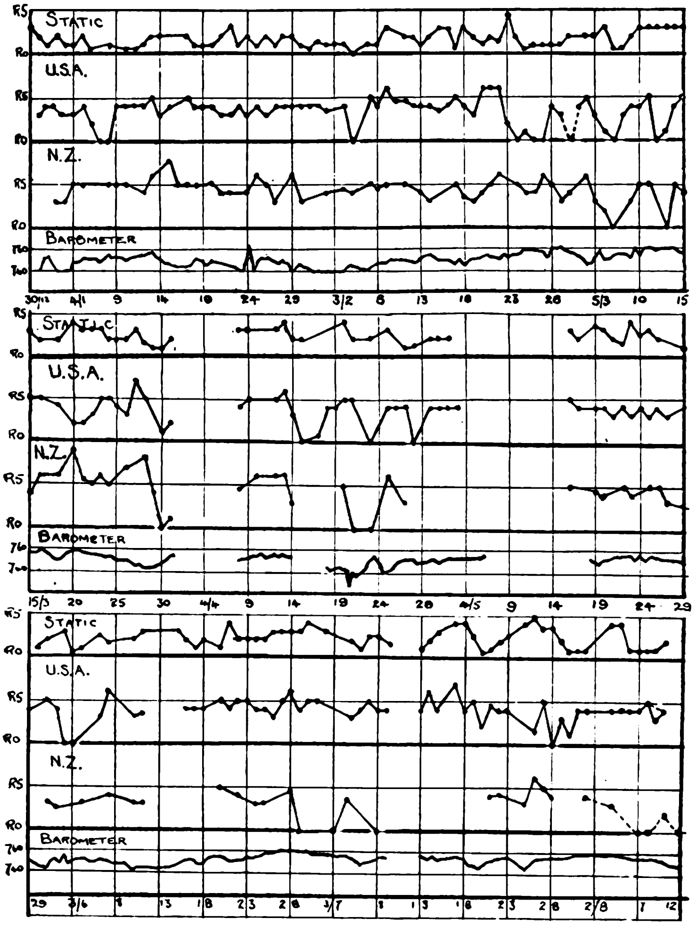


Fig. 2. *Extension of Fig. 1 to complete one year.*

The first thing which is apparent is that whenever there is a sudden change in the pressure, the signal strength of all districts is affected, the effect sometimes preceding,

and sometimes succeeding the pressure change. This in itself justifies the continuation of the work, as it indicates the existence of some relationship between the two. As an example, we will take the reception on and around 24th January. At this time it will be seen that the barometer had an exciting time, dropped fairly rapidly and rose very quickly again within a few hours. Signals from New Zealand, and also those from Brazil, rose to a very high value, and then dropped steadily. Those from the U.S.A., however, were not affected to any extent, except for a few hours, as shown by the log book. Now signals from New Zealand and Brazil come to England over practically the same great circle, whilst those from U.S.A. arrive by a path almost at right angles to that of the former, if we may assume that they travel by the shortest route, as is fairly reasonable. This point of the signals from the U.S.A. differing in behaviour from those from the south is well exemplified throughout the graphs, although there are cases where both are affected in the same manner. This would appear to indicate that some particular weather condition in the south, which might only show at the receiver as a slight change in the barometric pressure, might affect the signals crossing that area, whilst those arriving from the west without crossing that area would be unharmed. It then becomes obvious that it behoves us to look at other barometers that our own if we expect to learn the mechanism of the effects. The need became apparent to the writer soon after the beginning of the tests, for the reason shown above, and because many little effects were noticed which could not easily be drawn into the graphs. Accordingly, daily pressure charts were studied in conjunction with the log book.

That these effects are often local is shown by the fact that, in general, signals from both directions are affected at the same time, even if not in the same manner. A second point to be noted from the graphs is that a good settled barometer, a rare occurrence in this country, results in good strength of signals. If the weather did not play havoc with our short-wave signals, they might at least be good over long distances.

From a comparison of the graphs with the weather notes in the log book, it appears that the type of weather which favours "DX" in the winter is the dull, cold weather, and not the mild changeable sort, which produces more static than colder weather. In particular, there are always good signals on hand when snowy weather prevails. In the summer, it is the fine dry weather which is to be preferred, abnormally wet weather having a bad effect on signal strength. In general, then, weather which is in season is to be preferred, whilst weather out of season is not beneficial.

A little insight into the subject having thus been gained, a study of daily doses of isobars was commenced in early 1926, and this method revealed very much more than the former, as it might well be expected to do. Before a discussion of the results is attempted, however, it would be well to consider some modern ideas on the subject of wave propagation.

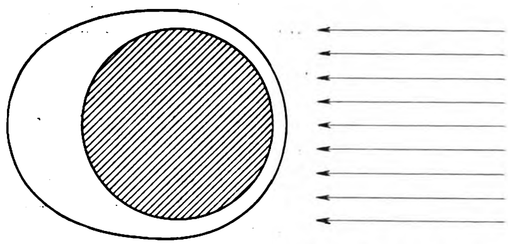


Fig. 3. *Showing changes in ionisation of the atmosphere between day and night.*

We have an earth, and surrounding it an atmosphere which is exposed to various celestial radiations, such as the ultra-violet waves from the sun, the result being that there is a tendency for the gases of the atmosphere to become ionised. By ionisation, is meant a dissociation of the molecules of the gases into parts bearing equal and opposite electric charges. There is always a tendency for these to recombine, but provided the ionising force remains constant, there will remain an equilibrium. The ionisation in the atmosphere varies considerably from place to place. At the surface of the earth there is very little, as the pressure of the superincumbent air is rather great, and also the ionising force is weak, the ionising radiations suffering considerable absorption during their passage through the atmosphere. As we recede from the surface of the earth the intensity

of ionisation gradually increases, as the pressure becomes less and the ionising force greater, but at great heights there is so little gas that however great the ionising force the intensity of ionisation cannot become very large. Hence there is a point some distance above the surface where the intensity of ionisation is greater than at any height above or any depth below.

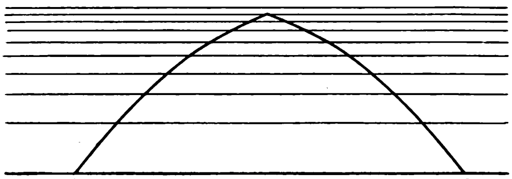


Fig. 4. *A wave group travelling through an electrically non-uniform medium.*

The effect of this ionisation as far as wireless waves are concerned is that ionised gas is a conductor of electricity, and that as a consequence wireless waves travel at a greater velocity in the conducting portions of the atmosphere than at the surface of the earth.

Now, if we imagine a wave group travelling off the earth at an angle to the surface, we shall have to give the waves a different velocity for each height as the group travels upwards. The result of this is that the track of the wave group will be bent toward the earth. Waves radiated at a fairly big angle will suffer this bending, or refraction, but will finally escape through the area of maximum ionisation or conductivity, but other waves sent off at a shallower angle will not be so fortunate, but will be bent toward the earth so much that they will eventually return to it, as shown in Fig. 4 where is shown the path of a wave group in a medium of increasing electrical density such as our atmosphere. The wave group travels upward and is gradually bent downward until its direction is in what is known as the critical angle, at which the denser medium refuses to transmit the waves, but totally reflects them. After reflection the wave group unbends itself, so to speak, and arrives back at the surface of the earth safe and sound, having suffered very little absorption in transit, the actual angle at which the waves must be projected to just achieve reflection is much less for short wavelengths than that shown in Fig. 4, and the shorter the wavelength, the less is this angle. A short wave will, for this reason, span a much greater distance in one reflection than a long one.* The effect of the wave groups returning to earth will present to observers situated at *A* and *B* exactly the same effect as would pure reflection, and the writer proposes here to consider the effect as such, for the purpose of simplicity. It can be shown that such treatment is legal, provided we keep within certain limitations. For the purpose of this article it will be sufficient to use the simpler treatment.

The sun's light is not present at the side of the earth which is in shadow, and consequently there will be a destruction of the equilibrium between the ionised particles and the ionising force, so that as the atmosphere is carried into the shadow with the advent of night time, de-ionisation sets in. Some ionising factor still remains, however, so that there still remains a conducting portion of the atmosphere, and the effect of the arrival of night may be regarded as a rising of the layers of conductivity to some much greater height, as represented in Fig. 3, where the line around the earth represents a contour of the maximum ionisation. Various figures are given for the two heights, which vary of course with the latitudes and the seasons as the amount of sunlight received varies; from 50 to 100 miles in the daytime and at night time of the order of 150 miles.

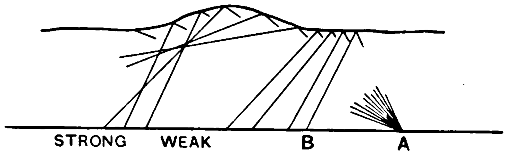


Fig. 5. *Reflection from a concave Heaviside layer.*

Now, considering the refracting medium as a single reflecting layer, suppose that there are undulations in this layer, as shown in Figs. 5 and 6, where is shown the paths of wave groups radiated at various angles from *A* and reflected down again to earth. It will be seen in Fig. 5, where the undulation is concave to the

* See *Q.S.T.*, October, 1925.

earth, that as we recede from A, we shall at first be in the well-known blind area of short waves, where no waves arrive from above because such would require to be reflected from the layer above at an angle greater than the critical angle, and where the only signal received is the badly attenuated direct wave along the surface. As we travel, the signals become weaker until they are inaudible. At some further distance, however, signals once more become audible, owing to the arrival of the downcoming waves. This point is represented by B in Fig. 5, but will not, in general, be very well defined, and the distance AB will depend on the wavelength and the height of the reflecting layer. In any case, waves of length greater than about 100 metres do not exhibit the blind area, since the ground wave arrives at B without experiencing sufficient absorption to render it inaudible, unless the power radiated from A is extremely small.

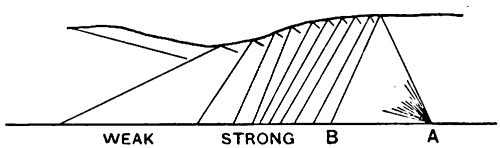


Fig. 6. *Reflection from a convex Heaviside layer.*

The effect of the concave disturbance will be that of bringing the signals from A to a focus, concentrating a good deal of the energy towards one point, so that as we recede somewhat farther from B than A, we shall find another area where signals are weak or inaudible. Still farther out we shall find a point where the energy is concentrated, and the signals are strong. It will be noticed that in the particular circumstances where the focus of the disturbance is at the surface of the earth we shall have a case of freak reception of very strong signals from A, which may be hundreds of miles distant.

In the case of Fig. 6, where the disturbance is convex, we shall find as we recede from A the usual blind area due to the signals experiencing a critical angle of reflection. From B onwards the signals will become increasingly stronger, the waves being thrown back from the sloping shelf, the first portion of the disturbance. Further on we come to a point where the signals become very weak again, having been brought to a virtual focus above the reflecting layer. The downward hump is acting as a screen or barrier to the waves. These two cases are the two simplest, and the effect of the waves which are reflected upward from the ground has not been shown. They will tend to complicate matters somewhat, but the total effect will be of the same nature as has already been shown for one reflection only.

Generalising the idea of irregularities in the reflecting layer, it may be said that a layer which slopes down towards the earth in the direction of wave propagation will tend to throw the wave back, and prevent it arriving at points beyond the region of the disturbance. Thus a disturbance in the nature of a downward hump will cast a real shadow behind it and the reverse before it.

From a study of the pressure distributions about the British Isles in conjunction with the logging of signals on 45 metres, the writer has come to the conclusion that effects of such a nature as have just been described exist in connection with cyclones and anti-cyclones and other distributions of barometric pressure. By daily comparing signals from different directions and comparing the passages of cyclones and anti-cyclones, it became apparent that signals were behaving in such a manner as would be expected were the reflecting layer higher than normal where the barometric pressure is high, and lower than normal where the pressure is lower than normal. Thus, for example, suppose that we have an area of low pressure over the North Sea, and an anti-cyclone off the West of Ireland. In this case we should expect, according to the above description, signals from the U.S.A. to be strong in England whilst on the Continent east of the depression they would be weak. Conversely, signals from the east will be weak. A very good example of this particular case has been noted at the time of writing. On the evening of 26th September, 1926, a fairly wide depression was centred off the east of England, and as the writer's receiver was practically beneath the centre, signals were not particularly good from any direction. By the following morning, however, an anti-cyclone had moved in to the west of Ireland, and the cyclone had moved slightly eastwards, the resultant field having a steep

pressure gradient from west to east: on this evening, 27th September, signals from the U.S.A. were received at enormous strength, the writer's station then being in the position marked "strong" in Fig. 6. At the same time, signals from the east had almost completely faded away, the only readable station being a German commercial station which was audible at about a hundredth of its normal strength. By the following morning conditions had not changed much, and a low power station in California was copied with ease, but by the evening the gradient west to east had become practically zero, and U.S.A. has returned to normal strength.

The type of field which is most common in this country consists of a high pressure area off the south-west, with a stream of cyclones travelling in the direction of the Gulf Stream to the north-east between Scotland and Iceland, giving a field which is usually favourable for the reception of signals from the south and south-west. Sometimes a cyclone runs off this track and crosses the British Isles and on such occasions as this the theory is supported very well indeed by observations. In the more general case, however, observations are often rendered difficult of interpretation because of the complicated nature of the field of pressure. It has been noticed that signals from Brazil and New Zealand are very strong when there is a steep pressure gradient in a north-westerly direction, such as when snowy weather is about.

Again, if we consider the sunset and sunrise and their effect on the reflecting layer we obtain some very interesting facts. It has been pointed out that at sunset a de-ionisation sets in and if we transfer the idea of a gradual de-ionisation as the earth turns round, to the convenient form, we have a gradual rising of the reflecting layer, and the net effect will be one of a slope in the layer travelling round the earth. The gradient will be upwards from daylight in the west to darkness in the east. Similarly at sunrise we shall have a slope in the reverse direction. Now applying the ideas of reflection of the waves from these sloping surfaces, we see that as sunset approaches, signals from the east will show a drop below daytime strength, followed by a rise to a high value as the layer passes overhead and throws extra energy back. After the slope has passed over, and darkness has set in, signals will settle down to their normal night time strength.

Considering the curve paths of signals in connection with these effects, we see that the real effect of the "sloping layer" is one of bending the end of the curved path, and as waves of different frequencies follow paths of different curvatures, it is to be expected that the throwing back of the waves will vary with the wavelength. This is evidenced by the fact that on the longer wavelengths the sunset and sunrise effects take place in the darkness, whilst on short wavelengths the effects are noticed before sunset and after sunrise. On 45 metres the rise in signal strength takes place at about an hour before sunset, whilst on 20 metres it happens much earlier.

If it so happens that sunrise here coincides with sunset at some other given point, transmission and reception between these two points will be very easy at such times. Thus in September, New Zealand is heard well here apart from local fluctuations, because at this time of the year the two phenomena of sunset and sunrise occur together here and in New Zealand.

The cause of the relation between pressure and intensity of ionisation has yet to be explained, and for this an intimate knowledge of the structure of the cyclone and the anti-cyclone is necessary. The disturbances of the atmosphere associated with these is known to extend to great heights, heights of the same order as is given for the Heaviside layer, the layer of maximum ionisation. The increased intensity of ionisation for a given height which the writer believes to exist over a cyclone may be due to an actual movement downwards of some of the air in high regions with a thinning out of the air in the regions previously occupied by them. Such a change would allow the air to maintain the same degree of ionisation as it would at its normal height. In connection with this, it is interesting to note that at the lower limit of the stratosphere, the region of steady temperature is lower where the pressure is low than where it is high. Thus the tropopause, the lower limit of the stratosphere, presents a similar distribution to the layer shown in Figs. 5 and 6, though its height is of course

much less, not exceeding ten miles. A theory of this nature has been put forward by Captain Sinclair.

As a conclusion, one or two amplifications of the ideas outlined in this article may prove interesting. Using the form of the reflecting layer, we can see that the direction of propagation of the signals can be changed slightly by humps in the layer. In Fig. 7 are shown two plans or maps, (A) of a cyclone, and (B) of an anti-cyclone, the circles representing contours of a particular degree of ionisation, and also isobars. Signals from a point A are shown by thick lines, the first dot on each line representing the point of reflection at the layer, and the second dot the point of arrival at the earth.

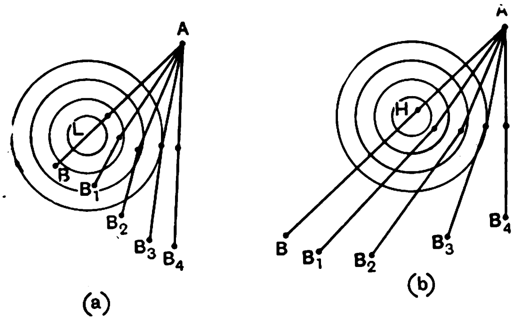


Fig. 7. *Change of direction of a signal passing through a cyclone or anticyclone.*

In each case it will be seen that the wave which passes squarely across the disturbance continues after reflection in the same vertical plane, but those which strike the disturbance obliquely are turned outwards in (A) and inwards in (B), arriving at B_1, B_2, B_3, etc., from the wrong apparent direction with the wrong direction of polarisation, and are no longer travelling in the vertical plane, as defined by A, B, and the point of reflection.

Another point of interest arises in connection with interference of two waves. It is possible for a signal to arrive at the receiver by two routes, particularly so in the light of the preceding paragraph, and as it is not very likely that these two paths will be of equal lengths, it is most probable that the E.M.F.s received will be of differing phases, giving a resultant E.M.F. which may be greater or less than that supplied by signals arriving by only one path. Now if the pressure system, with its attendant changes in the electrical properties of the atmosphere, is in a state of change or motion, the relative lengths of the two signal paths will also be in a state of change, with the result that the phases of the two received E.M.F.s will not be constant. The outcome of this on the resultant E.M.F. is a variation of the received signal strength of the type known as "fading." The same principle, applied to sunset and sunrise, can be made to account for the bad fading of short-wave signals noticed at these times.

The effects discussed, when applied to long distance transmission, can be applied at both ends, or any points in the path of the signals. If fading can be generated at the transmitter by some particular set of conditions it is less likely that there can be an integration of the signals which would otherwise be expected where great distances allow of many possible paths.

In the foregoing is outlined a fairly new theory which is being examined by the writer. It will have been noted that up to the present observations have been confined to one band of wavelengths only, and it is proposed to examine others in the same way. The reason for limitation to one band is not any previous assumption that this particular band would prove more fruitful than others, but simply that the experimental work was nothing more than an attempt to serve some useful purpose whilst being what is known in amateur circles as a "DX merchant." Indications have been received, however, that the phenomena explained are common to the broadcast wavelengths : in fact, it is expected that they will only vary with frequency in degree, in the same manner as day and night effects.

A Radio Signal-Intensity Recorder.

*By B. Saltmarsh (6SF).**

Introduction.

THIS instrument, as its name implies, was designed for the purpose of making a direct record of the intensity or strength of an incoming radio signal, and consequently of showing variations in such intensity.

Everyone who has tried to "reach out" with his radio receiver and has listened for signals from a distant station has, no doubt, noticed that the intensity of the signal is by no means constant. At one moment the signal may be quite strong and then, for no apparent reason, it suddenly dies away, often becoming quite inaudible. This dying away effect is commonly known as "fading," and from time to time various theories have been put forward to account for it.

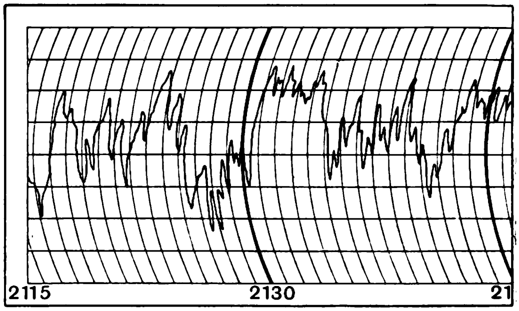
Present-day Theory on Fading.

The theory most generally accepted to-day is that every transmitter sends out two waves, one of which travels close to the earth, and is known as the "ground wave," while the other rises through the ether until it meets the Kennelly-Heaviside Layer by which it is turned or deflected back to earth. This is known as the "deflected wave."

Close to the transmitter the ground wave will be the stronger, but at distances of over 90 miles away, the deflected wave comes into operation. This figure—90 miles—is not by any means constant, owing to the fact that the frequency of the wave transmitted governs the angle of deflection to a considerable extent, but it constitutes a very rough average. At this distance the ground wave will have dropped off very much in intensity due to absorption, and the deflected wave may only give rise to a very weak signal by itself, but if it so happens that both the deflected and ground waves arrive at the receiver "in step" then the one will back up the other, and a comparatively strong signal will be the result. Some slight change then takes place in the ether. It may be that the level of the Kennelly-Heaviside Layer has altered at the point where the deflected wave strikes it, causing the angle of deflection to vary slightly, and the two waves to arrive out of step at the receiver. They may get out of step to such an extent that one wave will actually neutralise the other. The result will be that the signal strength will fall off till the two waves once more get into step and help, instead of neutralise, one another.

Early Tests and Investigations.

This, however, is merely a theoretical explanation and may be no more accurate than the many which have preceded it, and it was seen some years ago that it was a waste of time to theorise on a subject about which practically nothing was known.



A record typical of reception of a broadcast programme from a medium-power station over a distance of 80-100 miles. Note the short-period variations. The vertical lines indicate time. The horizontal lines are merely to facilitate the comparison of records. Only the first half of the record is shown, but is full size.

A series of tests was accordingly arranged and carried out both in this country and in America. In these early tests the human ear was the instrument used for detecting variations in the signal strength, the signals chosen being telephonic in preference to telegraphic, owing to their being continuous, and not cut up into the dots and dashes of the Morse code. The human ear, however, is not sensitive to very slight and rapid changes in sound intensity, nor is it

* Received by the Editor, December, 1926.

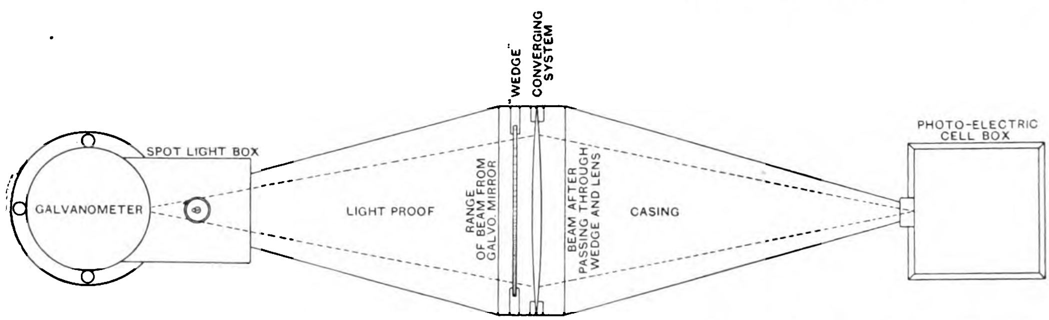
able easily to discriminate between such effects as a drop in sound volume on the part of that which is modulating the radio wave, be it orchestra, piano, or voice, and the actual drop in intensity of the carrier wave.

Earlier Recorders.

It was therefore obvious that if the tests were to be of any real value, the human element must be cut out, and the records must be made independently of it. An instrument was designed in America for this purpose,* in which the carrier wave, after suitable amplification and rectification by a stable crystal, actuated a reflecting galvanometer, the beam from which moved over a photographic sheet mounted on a revolving drum. The carrier wave thus drew its own intensity curve, but this instrument, although highly accurate and sensitive, necessitated the work being done in a dark room, and by an expert, while considerable delay was involved before the record was ready for examination owing to the photographic sheet having to be developed.

Another form of recorder in use in America was one in which the rectified carrier wave actuated a pointer galvanometer, the movements of the pointer being traced by hand by the operator on a revolving drum. This method has the advantage of not requiring expert operation, and is free from the delay necessitated by photographic processes, but it is less accurate than the photographic recorder, and is naturally more tiring to work.

In the instrument designed by the writer, the aim has been to eliminate both the human element and the photographic process, and yet to retain accuracy and simplicity of operation. The recorder is very simple to work, and does not require a dark room. It also has the advantage that the record is made in the open, so that it can be examined while it is being made. Therefore, if the operator is wearing phones, he can mark the record when he hears an atmospheric discharge or jamming from another station interfering with his signal, and when examining his record, he will be able to see if these occurrences appear to have had an adverse effect on his signal, or otherwise.



Plan showing general lay-out of apparatus. The distance between the lens and the aperture in the photo-electric cell box is such that all the light passing through the wedge is converged by the lens to fall on the aperture in the box. This distance having once been ascertained will not need alteration.

The Signal-Intensity Recorder.

The incoming carrier wave after passing through a sufficient number of stages of high-frequency amplification to bring it up to a suitable strength, is rectified by a stable crystal. The rectified current then actuates a reflecting galvanometer, and the beam from this galvanometer moves over what is optically known as a "wedge." This consists of a strip of coloured glass, the colouring matter being so arranged that the strip is almost opaque at one end, while at the other it is quite lightly tinted, the colour being very carefully graduated. From this it will easily be seen that if the spot-light, which supplies the light to the mirror of the galvanometer, is kept steady, and if the beam

* See *Proceedings of the Institute of Radio Engineers*, Vol. 10, No. 2, April, 1924, "Short Period Variations in Radio Reception," G. W. Pickard.

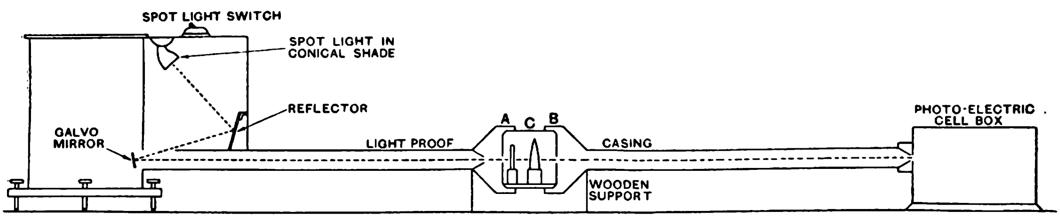
from the mirror travels backwards and forwards over this wedge, then the amount of light which passes *through* the wedge will be governed by the density of the wedge at the point where the beam strikes it, and will be proportional to the deflection of the galvanometer. Thus, when the signal is coming in at full strength, and the galvanometer is at its greatest deflection, the beam is focussed upon the lightly tinted end of the wedge, and the maximum amount of light passes through; but as the signal strength falls off the deflection of the galvanometer diminishes, and the beam moves over the wedge towards the more deeply tinted end, and the nearer to that end it gets, the less will be the amount of light which penetrates through the wedge. From this it will be seen that the quantity of light passing through the wedge varies directly as the intensity of the carrier wave.

Behind this wedge—*i.e.*, on the side opposite to the galvanometer—a condensing lens is placed, forming a converging system, its object being to focus the light passing through any position on the wedge on to one point. At this point a photo-electric cell is mounted. Such a cell, as is probably known, is highly sensitive to minute variations in the amount of light focussed upon it, its resistance varying very considerably for a very small change of light.

Now, since the photo-electric cell is governed by the quantity of light passing through the wedge, this quantity being directly controlled by the deflection of the galvanometer, which, in its turn, is controlled by the incoming signal, it is obvious that the resistance of the cell and the consequent flow of current is going to vary strictly in proportion to the variations in the intensity of the signal.

The current controlled by the photo electric cell then passes through several stages of low-frequency amplification and then actuates an electro-magnetically operated pen. This moves over a rotating drum carrying specially ruled paper and makes a graphical record of the strength of the incoming signal. The drum, which is 15 inches round, rotates once an hour, and as the paper on it is divided into 60 equal sections, each section representing one minute of time, the pen travels over a horizontal distance of a quarter of an inch per minute. This speed of working gives quite a nice open record, and enables the smaller variations to be clearly shown. When two or three such records are made at the same time of the same signal, but at different receiving stations, it is as well to have the records as open as possible to enable more accurate comparisons to be made.

Since the photo-electric cell is so sensitive to changes of light it has been found advisable to enclose the apparatus from the galvanometer to the cell in a light-proof box, as shown in the accompanying illustrations. If this were not done, the passage of the sun behind a cloud or, as is more likely in this country, the arrival of the sun from behind a cloud, would be quite sufficient to spoil a record, and it has been found easier to make the instruments light-proof than to keep them under the influence of a steady light.



Side view of apparatus. Note special arrangement of spot-light. The light-proof casing may be detached from the box containing the wedge and lens at A and B, as shown. The wedge and lens are so mounted that they may be slid into and out of C, and their distance from each other is thus made adjustable.

Mathematics for Wireless Amateurs.

By F. M. Colebrook, B.Sc., A.C.G.I., D.I.C.

(*Continued from page* 691 *of November issue.*)

PART IV (CONTINUED).

9. Combinations of Impedance.

(A) *Series.*

If any number of impedances

$$z_1=R_1+jX_1$$
$$z_2=R_2+jX_2 \text{ etc., etc.}$$

are connected in series as shown in Fig. 49, *i.e.*, so that the same current flows through each of them, then the application of

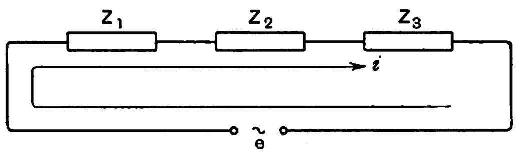


Fig. 49.

Kirchhoff's second law in its vector form will lead directly to the equation

$$(z_1+z_2+z_3+\text{etc.})\,\mathbf{i}=\mathbf{e}$$

i.e., $\mathbf{i}=\mathbf{e}/(z_1+z_2+z_3+\text{etc.})=\mathbf{e}/z$

where $z=z_1+z_2+z_3$ etc.
$=(R_1+R_2+R_3+\text{etc.})$
$+j(X_1+X_2+X_3+\text{etc.})$.

In other words the separate impedances are equivalent to a single impedance the components of which are given by the addition of the components of the individual impedances. The impedance operators are added together in accordance with the rules for the addition of such operators. If the individual impedances be represented as vectors, as explained in paragraph 7 (November) then the vector representing the single equivalent impedance is the vector sum of the separate vectors, as in Fig. 50.

(B) *Parallel.*

Consider first the case of two impedances in parallel, as shown in Fig. 51. Applying Kirchhoff's second law to the circuits $ABCDFA$ and $ABCEFA$ in succession gives the equations

$$\mathbf{e}-\mathbf{i}_1z_1=0 \text{ or } \mathbf{i}_1=\mathbf{e}/z_1$$
$$\mathbf{e}-\mathbf{i}_2z_2=0 \text{ or } \mathbf{i}_2=\mathbf{e}/z_2$$

Further, applying Kirchhoff's first law to the point C

$$\mathbf{i}=\mathbf{i}_1+\mathbf{i}_2$$

Therefore

$$\mathbf{i}=\frac{\mathbf{e}}{z_1}+\frac{\mathbf{e}}{z_2}=\mathbf{e}\left(\frac{1}{z_1}+\frac{1}{z_2}\right)=\frac{\mathbf{e}}{z}$$

where

$$\frac{1}{z}=\frac{1}{z_1}+\frac{1}{z_2}$$

Thus the two impedances z_1 and z_2 in parallel are equivalent to a single impedance related as above to the individual impedances. The result can obviously be extended to the case of any number of impedances in parallel giving

$$\frac{1}{z}=\frac{1}{z_1}+\frac{1}{z_2}+\frac{1}{z_3}+\frac{1}{z_4} \text{ etc., etc.}$$

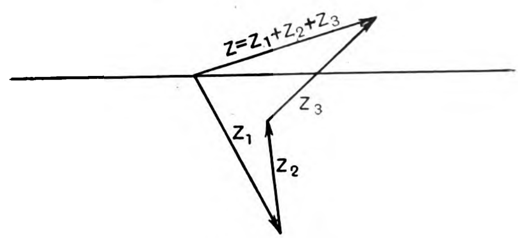


Fig. 50.

10. Graphical Representation of Impedances in Parallel.

Parallel combinations of impedances play a very large part in the technique of wireless communication, having interesting and valuable properties which arise from the complex reciprocal relationships described

above. These properties are most easily apprehended in graphical form, and it is, therefore, proposed to describe some simple constructions. One of these, corresponding to the general case, has probably not been published in this country before.

(A) *Impedances of Equal Phase Angle.*

If two impedances are of equal phase angle, *i.e.*,

$$z_1 = Z_1\epsilon^{j\theta}$$
$$z_2 = Z_2\epsilon^{j\theta}$$

the impedance equivalent to these in parallel can be drawn as in Fig. 52*a*. AC is any

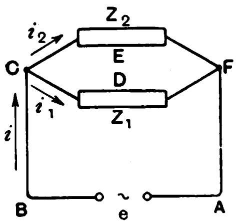


Fig. 51.

convenient distance. The rest of the construction is obvious. The proof is as follows:—

$$\frac{z}{z_1} = \frac{Z\epsilon^{j\theta}}{Z_1\epsilon^{j\theta}} = \frac{Z}{Z_1} = \frac{BC}{AC}$$

and similarly

$$\frac{z}{z_2} = \frac{AB}{AC}$$

Therefore

$$\frac{z}{z_1} + \frac{z}{z_2} = \frac{AB}{AC} + \frac{BC}{AC} = \frac{AC}{AC} = 1$$

i.e.,

$$\frac{1}{z} = \frac{1}{z_1} + \frac{1}{z_2}$$

Notice that the equivalent impedance is of the same phase angle as the component impedances and necessarily less in magnitude than either.

Important special cases are

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

for two resistances in parallel, and

$$\frac{1}{j\omega L} = \frac{1}{j\omega L_1} + \frac{1}{j\omega L_2} \; i.e. \; \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$

for pure inductances in parallel (provided there is no mutual inductance). (*Note* that since the impedance of a condenser of capacity C is $1/j\omega C$, as already shown,

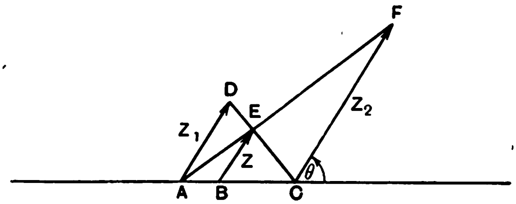


Fig. 52a.

capacities in parallel combine by simple addition, *i.e.*,

$$C = C_1 + C_2$$

For condensers in series, on the other hand, we have by the addition of the separate impedances an equivalent single capacity given by

$$\frac{1}{j\omega C} = \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} \; i.e. \; \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

a relationship to which the above construction applies. This apparent reversal of the laws of series and parallel combination in the case of capacities is simply due to the fact that the impedance of a condenser is already in the form of a reciprocal).

(B) *Impedances of Opposite Phase Angle.*

i.e.,
$$z_1 = Z_1\epsilon^{j\theta}$$
$$z_2 = Z_2\epsilon^{j(\theta+\pi)} = -Z_2\epsilon^{j\theta}$$

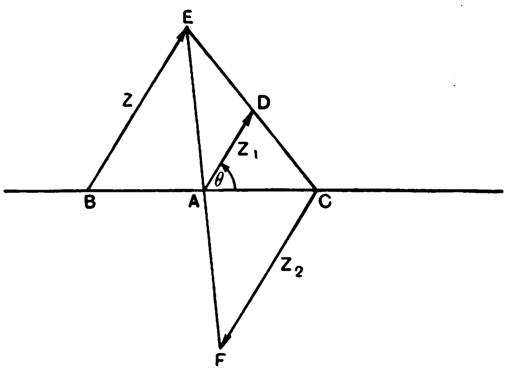


Fig. 52b.

The construction for this case is shown in Fig. 52*b*, and is carried out in exactly the same way as for (A). The proof also is

the same except that we shall now have

$$\frac{z}{z_2} = -\frac{Z}{Z_2} = -\frac{AB}{AC}$$

which will lead to

$$\frac{z}{z_1} + \frac{z}{z_2} = \frac{CB - AB}{AC} = \frac{AC}{AC} = 1$$

from which the desired result follows.

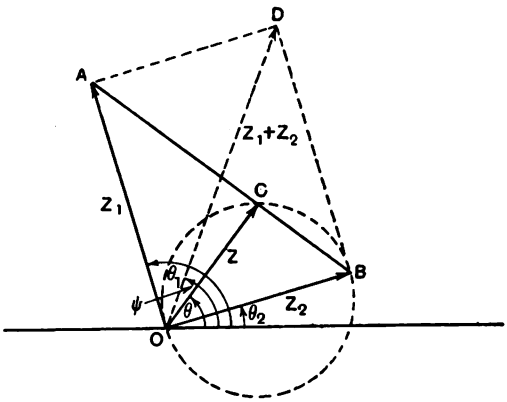


Fig. 53.

A very important special case of this is given by a pure capacity and a pure inductance in parallel. It will be found that if the impedances of these are equal in magnitude, *i.e.*, if $\omega L = 1/\omega C$ the lines CE and FE become parallel, *i.e.*, E goes to infinity and the equivalent impedance is infinite. The case is never realised in practice, of course, since it is impossible to get either a capacity or an inductance without some small resistance term, which limits the resultant impedance, but the construction throws some light on the behaviour of such a combination.

Both of the above cases (equal and opposite phase angle) have already been described by the writer in a slightly less general form in this journal (December, 1924), and readers are advised to refer to this.

(c) *Phase Angles differing by Ninety Degrees.*

For instance, a pure resistance and a pure reactance, or more generally,

$$z_1 = Z_1 \epsilon^{j\theta_1}$$
$$z_2 = Z_2 \epsilon^{j\theta_2} = Z_2 \epsilon^{(j\theta_1 - \pi/2)}$$

Let OA and OB in Fig. 53 represent z_1 and z_2 respectively. Join AB. Draw OC perpendicular to BA. Then OC represents z, the impedance equivalent to z_1 and z_2 in parallel. For proof, complete the rectangle as shown by the dotted lines. Then OD represents $z_1 + z_2$, in magnitude and phase.

Now,

$$\frac{z_1}{z} = \frac{Z_1 \epsilon^{j\theta_1}}{Z \epsilon^{j\theta}} = \frac{Z_1}{Z} \epsilon^{j(\theta_1 - \theta)} = \frac{OA}{OC} \epsilon^{j(\theta_1 - \theta)}$$

Also

$$\frac{z_1 + z_2}{z_2} = \frac{OD \epsilon^{j\psi}}{OB \epsilon^{j\theta_2}} = \frac{OD}{OB} \epsilon^{j(\psi - \theta_2)}$$

But the triangles OCA and OBD are similar. Therefore,

$$\frac{OD}{OB} = \frac{OA}{OC}$$

and

$$(\psi - \theta_2) = B\hat{O}D = C\hat{O}A = (\theta_1 - \theta)$$

so that

$$\frac{z_1 + z_2}{z_2} = \frac{OA}{OC} \epsilon^{j(\theta_1 - \theta)} = \frac{z_1}{z}$$

i.e.,

$$\frac{1}{z} = \frac{z_1 + z_2}{z_1 z_2} = \frac{1}{z_1} + \frac{1}{z_2}$$

Notice further that if OB remains constant while OA varies in magnitude the locus of C is a circle on AB as diameter (since $O\hat{C}B$ is a right angle for all values of OA).

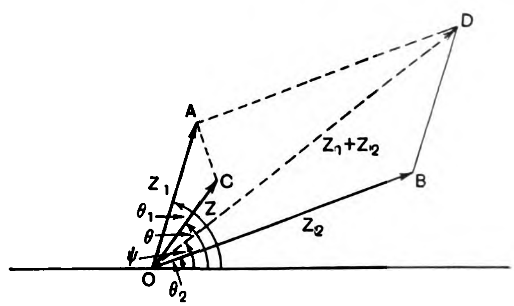


Fig. 54.

This construction also was described, in a slightly less general form and with a less satisfactory proof, in the article referred to above, in which a practical application of the construction to a "wireless" problem was also given.

(D) *A general Construction for any Two Impedances in Parallel.*

The following construction, which the writer ought to have discovered for himself as an obvious generalisation of the foregoing special case, is taken from the *Wechselstromtechnik* of Dr. Arnold.

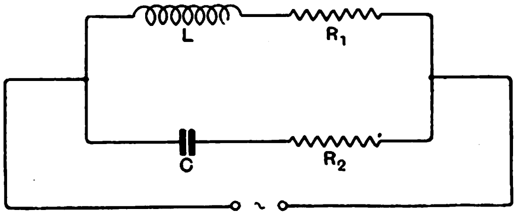


Fig. 55.

If OA and OB in Fig. 54 represent the impedances z_1 and z_2, complete the parallelogram $OADB$, and draw the triangle OCA similar to OBD. Then OC represents z, the impedance equivalent to z_1 and z_2 in parallel. The proof is word for word as in (C) above.

It would be easy to multiply examples of the application of the above rules for the combination of impedances and of the above graphical constructions but space cannot be given to this in a series which is intended to deal more with general technique than with individual problems. Various articles which have appeared in this journal will supply illustrative and useful examples —for instance that by W. A. Barclay in the issue for February, 1927. One peculiar case may, however, be brought to the notice of readers. If in the circuit shown in Fig. 55 $R_1=R_2=R$ and $L=CR^2$, then it can be shown that with respect to the external E.M.F. $e=\hat{e}\sin\omega t$ the circuit will behave like a non-inductive resistance at all frequencies. It will be a useful exercise to demonstrate this and to determine the magnitude of the resistance.

11. Coupled Circuits.

(A) *Mutual Inductance.*

Two inductive circuits so disposed that the magnetic field produced by a current in either is linked with the other, *i.e.*, cannot be removed without cutting the other, are said to possess a mutual inductance. Any change in the current flowing in either circuit will give rise to a change in the "flux linkages" of the other, *i.e.*, will give rise to an **E.M.F.** in the other circuit. The E.M.F. induced in either circuit by a change in the current in the other is proportional to the rate of this change. The mutual inductance M between two inductances L_1 and L_2 carrying currents i_1 and i_2 is so defined that the E.M.F. induced in L_1 by any change in i_2 is given in magnitude by $M(di_2/dt)$. It is an electrical proposition for which space cannot be spared that for the same circuits the E.M.F. induced in L_2 by any change in i_1 is given in magnitude by $M(di_1/dt)$. As far as sign is concerned a new convention is required, for that already laid down refers only to the currents and potential differences of a single circuit. Actually it will appear later that as far as either circuit is concerned individually the sign attributed to the mutual inductance is quite immaterial, but for interpreting the relation between the primary and secondary currents a sign convention is desirable. There is no universally agreed convention, but for the present purpose it will be taken that currents in the two circuits are of the same sign if each tends to increase the "flux linkages" due to the other. With this understanding it will be

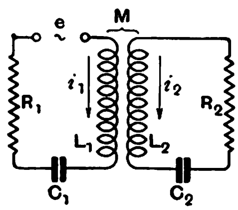


Fig. 56.

found that a negative sign must be attributed to the E.M.F. due to mutual induction. The vectorial forms for the mutually induced E.M.F.s will obviously be—$M\omega j\mathbf{i}_2$ and —$M\omega j\mathbf{i}_1$.

Consider now the circuits shown in Fig. 56. That containing the external E.M.F. will be referred to as the primary circuit, and the other as the secondary. Kirchhoff's second law applied to these circuits will give

$$\mathbf{e}-(R_1+jX_1)\,\mathbf{i}_1-M\omega j\,\mathbf{i}_2=0$$

or

$$(R_1+jX_1)\,\mathbf{i}_1+M\omega j\,\mathbf{i}_2=\mathbf{e}$$

(for the primary)

and $(R_2+jX_2)\mathbf{i}_2+M\omega j\,\mathbf{i}_1=0$
(for the secondary)

where

$$X_1=\omega L_1-1/\omega C_1$$

and

$$X_2=\omega L_2-1/\omega C_2$$

From the second of these equations

$$\mathbf{i}_2=-\frac{M\omega j}{R_2+jX_2}\mathbf{i}_1$$

$$=-\frac{M\omega j\,(R_2-jX_2)}{Z_2^2}\mathbf{i}_1$$

where $Z_2^2=R_2^2+X_2^2$

and substituting in the first equation this value of $\mathbf{i}_2$ in terms of $\mathbf{i}_1$

$$\left\{(R_1+jX_1)+M^2\omega^2\frac{(R_2-jX_2)}{Z_2^2}\right\}\mathbf{i}_1=\mathbf{e}$$

i.e.,

$$[\{R_1+(M^2\omega^2/Z_2^2)R_2\}+j\{X_1-(M^2\omega^2/Z_2^2)X_2\}]\mathbf{i}_1=\mathbf{e}$$

or

$$\mathbf{i}_1=\frac{\mathbf{e}}{\{R_1+(M^2\omega^2/Z_2^2)R_2\}+j\{X_1-(M^2\omega^2/Z_2^2)X_2\}}$$

All the interesting and useful properties of the above coupled circuits are implicit in the above two equations for $\mathbf{i}_2$ in terms of $\mathbf{i}_1$ and for $\mathbf{i}_1$ in terms of $\mathbf{e}$ and a whole series of articles could easily be written on the basis of these equations. The most important general deduction is that in consequence of the mutual inductive coupling the two circuits are virtually a single system so that no electron can agitate itself in the one without producing responsive tremors in the other. In particular the resistance of the primary circuit is increased by a certain fraction of the resistance of the secondary and its reactance diminished by the same fraction of the reactance in the secondary circuit. Considering this latter effect more closely—if the capacities are made infinite (which amounts to the same thing as short-circuiting them) and if the resistance of the secondary circuit is such that R_2^2 is negligible compared with $\omega^2L_2^2$, then the effective reactance of the primary circuit can be expressed in the form

$$\omega L_1(1-M^2/L_1L_2)$$

The quantity $M/\sqrt{L_1L_2}$ is called the coefficient of coupling and it approaches the value unity as the coupling is made closer and closer. Thus the effect of a short-circuited low resistance close-coupled secondary circuit is practically to wipe out the inductance of the primary. On the other hand, notice that if X_2 is made zero, as it can be by suitable variation of ω or of C_2 the effective reactance of the primary is unchanged, a fact which can be used experimentally to establish the condition $X_2=0$.

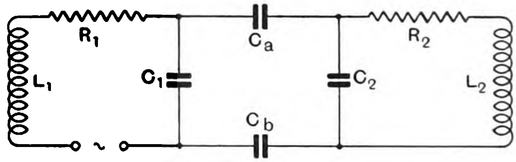


Fig. 57.

Considering further the case in which the circuits do not include the capacities, notice that if R_2^2 is small compared with $\omega^2L_2^2$ (a condition very easy to realise at radio frequencies) then the amplitudes of the primary and secondary currents are related by

$$\frac{i_2}{i_1}=\frac{M}{L_2}$$

a ratio which is independent of frequency. This fact has been turned to valuable account by Dr. Dye, of the National Physical Laboratory, in the design of radio-frequency current transformers for measurement purposes.

(B) *Capacitative Coupling.*

A network such as that shown in Fig. 57 in which the capacities C_a and C_b are in general of relatively small magnitude, has properties very similar to those of the inductively coupled circuits considered above and are therefore described as capacitatively coupled circuits. Space cannot be given to the detailed analysis of this arrangement but the methods described and illustrated in the inductive case should suffice for the reader who wishes to study it. In this connection it may be pointed out that at radio frequencies exceedingly small capacities will suffice to produce coupled circuit phenomena. In fact the unintentional stray capacities of any such system are in general quite sufficiently large to produce appreciable coupling effects, so that the loosely coupled circuits of modern wireless practice are in

general both inductively and capacitatively coupled and are likely to exhibit the characteristics of both types of coupling unless suitable screening arrangements are used.

The above two types do not, of course, exhaust the possibilities of coupled systems, which may and frequently do contain more than two closed circuits coupled in a variety of ways. However, Kirchhoff's laws and the vector methods described in these articles provide a perfectly general method of analysis of all such arrangements.

12. Damped Oscillations.

The alternating currents so far considered have been currents of constant amplitude for the maintenance of which some external source of E.M.F. is required. There is another type of alternating current which is of importance in electrical theory—that of which the "alternations" or "oscillations" are analogous to those of a tuning fork or pendulum or similar mechanical system, which, when displaced in any way from its normal condition of rest vibrates freely with diminishing amplitude and finally comes to rest again. The general type of such alternating currents is $i = \hat{\imath}\epsilon^{-kt} \cos(\omega t + \theta)$ where k is a positive number. Fig. 58 is the picture of such a current.

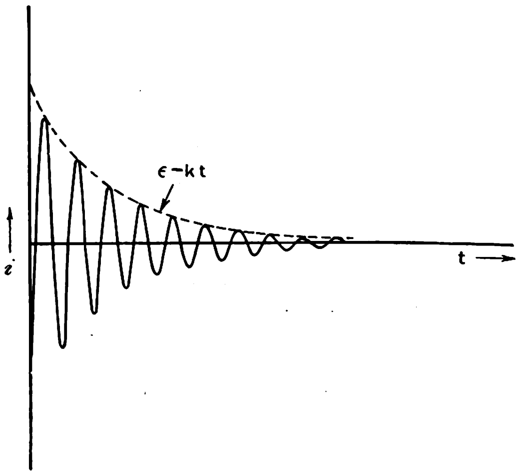


Fig. 58.

It was shown in paragraph 12 (October, 1927) that such an oscillation can be represented by a vector $\mathbf{i}$ of exponentially decreasing magnitude $\hat{\imath}\epsilon^{-kt}$, rotating with constant angular velocity ω. It was also shown that for such a vector

$$d\mathbf{i}/dt = (-k + \omega j)\mathbf{i}$$

Following exactly the same steps as in paragraph 4 (November, 1927) it is easy to show that the back E.M.F.s e_R, e_L, and e_C produced by such a current in a resistance R, an inductance L and a capacity C respectively are represented by the vectors

$$\mathbf{e}_R = -R\mathbf{i}$$

$$\mathbf{e}_L = -(\omega j - k)L\mathbf{i}$$

and $$\mathbf{e}_C = -\frac{\mathbf{i}}{(\omega j - k)C} = \frac{(\omega j + k)}{(\omega^2 + k^2)C} \cdot \mathbf{i}$$

Now, consider the simple series circuit shown in Fig. 44 (November, 1927) and imagine that at the instant when the current in the circuit has the value i_0 the source of E.M.F. is replaced by a short circuit. It is obvious on physical grounds that the current cannot fall to zero instantaneously, but as long as it continues to flow it must be such as to require no external source of E.M.F. to maintain it, *i.e.*, by Kirchhoff's second law, in its vectorial form,

$$\mathbf{e}_R + \mathbf{e}_L + \mathbf{e}_C = 0$$

Now, it is easy to show that for certain values of k and ω this condition is satisfied by a damped oscillatory current of the type considered above, for

$$\begin{aligned}
&\mathbf{e}_R+\mathbf{e}_L+\mathbf{e}_C \\
&= -R\mathbf{i} - (\omega j - k)L\mathbf{i} - \frac{\mathbf{i}}{(\omega j - k)C} \\
&= -\left\{R + (\omega j - k)L - \frac{(\omega j + k)}{(\omega^2 + k^2)C}\right\}\mathbf{i} \\
&= -\left[R - k\left\{L + \frac{1}{(\omega^2 + k^2)C}\right\}\right. \\
&\qquad \left. + \omega j\left\{L - \frac{1}{(\omega^2 + k^2)C}\right\}\right]\mathbf{i}
\end{aligned}$$

Now, if the values of k and ω are such that $\omega^2 + k^2 = 1/LC$ this becomes

$$\mathbf{e}_R + \mathbf{e}_L + \mathbf{e}_C = -\{R - k(2L)\}\mathbf{i}$$

so that if in addition $k = R/2L$

$$\mathbf{e}_R + \mathbf{e}_L + \mathbf{e}_C = 0$$

We have shown therefore that a current

$$i = \hat{\imath}\epsilon^{-kt} \cos(\omega t + \theta)$$

where

$$k = R/2L$$

and

$$\omega^2 + k^2 = 1/LC \quad i.e., \quad \omega^2 = \frac{1}{LC} - \frac{R^2}{4L^2}$$

will satisfy the requirements of the problem. It can, moreover, be shown that this is the *only* current which will satisfy the requirements, but the proof is beyond the scope of these articles. Also we have not yet determined the quantities $\hat{\imath}$ and θ. These, however, can be determined if required by other conditions that the current has to satisfy. For instance, if time is reckoned from the instant when the external E.M.F. is removed, we have the condition that $i = i_0$ when $t = 0$, whence

$$i_0 = \hat{\imath} \cos \theta.$$

Further since the back E.M.F. across the inductance cannot change instantaneously its value at $t=0$ will be that corresponding to the immediately preceding steady state condition, which can be determined as shown in paragraph 8. Thus $-L(di/dt)$

$$= \omega L\hat{\imath}\epsilon^{-kt} \sin(\omega t + \theta) + kL\hat{\imath}\epsilon^{-kt} \cos(\omega t + \theta)$$

so that

$$-L(di/dt)_{t=0} = \omega L\hat{\imath} \sin\theta + kL\hat{\imath} \cos\theta$$

and since the value of this is known we have two equations for determining $\hat{\imath}$ a θ.

Generally speaking, however, it is the type, the damping factor k and the periodicity $2\pi/\omega$ that one is more interested in, and these are determined as shown. Notice that the current at any instant t is

$$\hat{\imath}\epsilon^{-kt} \cos(\omega t + \theta)$$

and at a complete period later, *i.e.*, at the instant $t = T$, it will be

$$\hat{\imath}\epsilon^{-k(t+T)} \cos\{\omega(t+T)+\theta\} = \hat{\imath}\epsilon^{-kt}\epsilon^{-kT} \cos(\omega t+\theta)$$

The ratio of the first of these to the second is therefore ϵ^{kT}, which is independent of t, *i.e.*, a constant with respect to t. The logarithm of this ratio to the base ϵ is kT, which is called the "logarithmic decrement" of the circuit.

Circuits more complicated than the simple case considered will permit of a number of simultaneous "free oscillations." These will, however, be of the same general type as the example given, differing only in frequency and damping factor, and the above method of vector analysis will still apply. For further information the reader is referred to *Electric Oscillations and Electric Waves* by G. W. Pierce (McGraw-Hill) or to the writer's own book *Alternating Currents and Transients* (McGraw-Hill).

13. Power in Alternating Current Circuits.

Consider a conductor carrying a current i the potential difference between the ends of the conductor being e. It is a matter of elementary electrical theory that electrical energy is being absorbed by the conductor at a rate proportional to the product, *i.e.*, this energy being transformed into some other kind of energy (heat, motion, or chemical energy). The practical units are so chosen that if i is expressed in amperes and e in volts the rate of absorption or transformation of energy is, *ie* "joules" per second, or, otherwise expressed, the power is ie watts. If i and e are varying quantities, as in alternating current circuits, the relation still holds at any given instant considered. Thus if $e = \hat{e} \cos \omega t$ and $i = \hat{\imath} \cos (\omega t - \phi)$ then the instantaneous power absorbed by the conductor is

$$ie = \hat{\imath}\hat{e} \cos \omega t \cos (\omega t - \phi)$$

Now, as shown in Part II,

$$\cos A \cos B = \tfrac{1}{2}\{\cos(A+B) + \cos(A-B)\}$$

Applying this to the present instance

$$ie = \frac{\hat{\imath}\hat{e}}{2} \cos \phi + \frac{\hat{\imath}\hat{e}}{2} \cos (2\omega t - \phi)$$

and is seen to consist of a constant term $\frac{1}{2}\hat{\imath}\,\hat{e} \cos \phi$ and a double frequency periodic term. The mean value of ie over a complete period (*i.e.*, from $t = 0$ to $t = T = 2\pi/\omega$) is (see paragraph 15, October, 1927).

$$\frac{1}{T}\int_0^T ie\, dt$$

$$= \frac{1}{T}\int_0^T \frac{\cos\phi}{2}dt + \frac{1}{T}\int_0^T \frac{\cos(2\omega t - \phi)}{2}dt$$

$$= \frac{1}{T}\,\frac{\hat{\imath}\hat{e}\cos\phi}{2}\int_0^T dt + \frac{1}{T}\,\frac{\hat{\imath}\hat{e}}{2}\int_0^T \cos(2\omega t - \phi)dt$$

$$= \frac{1}{T}\,\frac{\hat{\imath}\hat{e}\cos\phi}{2}\Big[t\Big]_0^T + \frac{1}{T}\,\frac{\hat{\imath}\hat{e}}{2}\left[\frac{\sin(2\omega t - \phi)}{2\omega}\right]_0^T$$

$$= \frac{1}{T}\,\frac{\hat{\imath}\hat{e}\cos\phi}{2}(T-0) + \frac{1}{T}\,\frac{\hat{\imath}\hat{e}}{2}\,\frac{1}{2}\,\frac{(\sin-\phi - \sin-\phi)}{2\omega}$$

$$= \frac{\hat{\imath}\hat{e}}{2}\cos\phi$$

In connection with alternating current circuits the term "power" is always taken to mean the mean value of the instantaneous

power over a period. Notice that the vector representation of the alternating currents and potential differences concerned leads to a very simple expression for the power, for ϕ is the angle between the vectors **i** and **e** and the mean power is therefore half the scalar product of these vectors, *i.e.*,

$$P = \tfrac{1}{2}(\mathbf{i}\cdot\mathbf{e}) = \tfrac{1}{2}(\hat{\imath}\,\hat{e}\cos\phi)$$

In this way it is easy to show that the resistance term is the power absorbing component of a general impedance, for if

$$\mathbf{i} = \mathbf{e}/(R + jX) \text{ or } \mathbf{i}(R + jX) = \mathbf{e}$$

then

$$P = \tfrac{1}{2}(\mathbf{i}\cdot\mathbf{e}) = \tfrac{1}{2}(R + jX)\mathbf{i}\cdot\mathbf{i} = \tfrac{1}{2}R(\mathbf{i}\cdot\mathbf{i}) + \tfrac{1}{2}X(j\,\mathbf{i}\cdot\mathbf{i})$$

Now, as shown in paragraph 11 (June, 1927), $\mathbf{i}\cdot\mathbf{i} = \hat{\imath}^2$ and $j\,\mathbf{i}\cdot\mathbf{i} = 0$ (since these two vectors are mutually perpendicular). Therefore

$$P = \tfrac{1}{2}\hat{\imath}^2 R$$

The X or reactance term is thus seen to be "wattless." The above process is equivalent to resolving the potential difference **e** into two terms one in phase and the other 90 degrees out of phase with the current **i**. In a similar manner the current can be resolved into two terms $R\mathbf{e}/Z$ and $jX\mathbf{e}/Z$ where $Z^2 = R^2 + X^2$, which are respectively in phase and 90 degrees out of phase (or in "quadrature") with **e**. The corresponding expression for P is

$$P = \tfrac{1}{2}\hat{e}^2 R/Z$$

showing that it is only the "in phase" component of i which is associated with power.

If in the above analysis we put $e = i$ it can be shown that the square root of the mean value of i^2, *i.e.*, of $\hat{\imath}^2\cos^2(\omega t - \phi)$ over a period is $i/\sqrt{2}$. Similarly the root-mean-square (or R.M.S.) value of e is $\hat{e}/\sqrt{2}$. Putting I and E for these R.M.S. values the above expressions become

$$P = I\,E\cos\phi = I^2R = E^2R/Z^2$$

14. Conclusion.

At the end of the last article of a very long series the writer can only hope that he has well and truly laid the foundations of the mathematical technique of elementary electric circuit theory. The space available for specific instances has of necessity been very limited, for the series has been concerned with general principles of technique rather than particular problems. More detailed application of the ideas will be found in the book by the writer referred to above. However, the real purpose of this final word is not to advertise a book of which the merits, viewed in retrospect, appear less obvious than the defects, but rather to avoid concluding with a paragraph numbered 13.

Answers to Examples in November Issue.

1. (*a*) $10 + 329.3j$.
   (*b*) $i = 30.37 \times 10^{-6}\cos(2\pi \times 830 \times 10^3 t - \phi)$. where $\tan\phi = 32.93$.
   (*c*) $368.5\mu\mu F$.
   (*d*) 52.12.

Notes on the Accuracy of Variable Air Condensers for Wavemeters.

By W. H. F. Griffiths, A.M.I.E.E., Mem.I.R.E.

IT is not *essential* that one should know with great accuracy the capacity, wavelength, or frequency corresponding with settings of variable air condensers used as means of tuning radio-receivers to resonance with incoming signal E.M.Fs. It is sometimes *desirable* that variable condensers of complicated receivers should have a reasonable degree of accuracy so that one or more of its circuits may be calibrated in order to simplify tuning adjustments.

The variable condensers of apparatus such as wavemeters must, however, have an accuracy of calibration as high as possible. Accuracy is, in fact, the first essential quality of a wavemeter condenser, varying grades of wavemeters requiring variable condensers of varying degrees of precision.

There are many factors to be taken into consideration in the estimation of the overall accuracy of a variable air condenser. In order to have, at all times, a complete knowledge of the accuracy of such a condenser at any scale reading it is necessary not only that it should have been calibrated against a standard of known accuracy, but also that it should have a degree of mechanical perfection sufficiently high to ensure that it "holds" this calibration.

The actual measurement or calibration of the variable condenser, whether it be in terms of capacity, or in terms of the wavelength or frequency of a circuit with which it is associated, depends primarily upon the accuracy of the standard or sub-standard instrument against which it is to be compared. The standard should, of course, be of a higher degree of precision than that of the condenser being calibrated. Assuming this and an ample sensitiveness of method, the accuracy with which the calibration can be transferred from the standard to the test condenser depends upon :—

1. The actual order of capacity of the condenser. The capacity of the condenser should not be too low and it should preferably have its zero "set-up" by another *air* condenser of fixed value.

2. The completeness of the screening of the condenser under test ; this becomes more serious in condensers having very low capacities.

3. The quality of the bearing of the rotary conductor system.

4. The freedom from any "back-lash" between the rotary plates themselves and the actual device by which their angular position is indicated.

5. To some extent upon the temperature at which the calibration is being performed.

6. The closeness with which the scale can be either read or set to a given value.

7. The number of points throughout the range of the condenser at which calibration is effected.

The accuracy with which the condenser, once calibrated, will "hold" this calibration over a period of time will depend upon :—

1. The quality of the bearing of the rotary conductor system. It must be sufficiently good to prevent any movement of this conductor system except that of true rotation about the axis of the shaft, *i.e.*, there must be absolute freedom from "end play" and "side play." Moreover, the bearing must not "wear."

2. True rotation of the moving plates. Each moving plate should rotate truly parallel with, and exactly midway between, the pair of fixed plates with which it interleaves. It would seem at first that this truth of rotation is only important in so far as it affects the uniformity of the law of the condenser, but it has an even more direct bearing upon calibration constancy because of the inverse law effect* which operates when an exact equalisation of

* See the author's article in *E.W. & W.E.*, Jan., 1926.

all the dielectric gaps has not been effected or is destroyed by want of truth of rotation.

3. A mechanical rigidity of each conductor system as a whole.

4. The mutual mechanical rigidity of the conductor systems, *i.e.*, the perfect rigidity of the solid insulating material with which the two systems are mechanically separated. This rigidity must be considered taking into account the effects of age, temperature, and shock.

5. The gradual natural distortion of the conductor plates themselves, especially the moving plates, by plate sagging or due to residual stresses remaining in the plates at the time of calibration.

6. The geometrical permanence of the scale both with age and temperature variation; by no means negligible in some materials.

The accuracy with which the condenser, once calibrated, can be set to a given value of C, λ or f, or with which a given scale reading can be stated and interpreted will depend upon :—

1. The perfection of screening.

2. The closeness with which the scale divisions can be read or set.

3. The angular displacement of the required setting from the nearest point for which a calibration exists. If the original calibration was not effected at a sufficient number of points a serious interpolation error may be present if the conformity to the general law of capacity change is not good.

4. To some extent, perhaps, upon temperature.

5. To some extent, possibly, upon the smoothness with which rotation can be effected. The moving system must be capable of gradual rotation by infinitely small angular increments in order to give freedom from "jumpy" adjustments which frequently prevent the exact setting of the system at a given position.

The above enumeration of qualities is intended only as a guide to the selection of a suitable variable condenser for wavemeters and other measuring apparatus, and it is not the author's intention to amplify them. It is intended, however, to explore more fully the inaccuracy introduced by reading a condenser scale.

The Accuracy of Scale Reading.

The accuracy with which the scale can be read or set may become an important factor in the overall accuracy of a condenser of precision. The closeness of reading depends, of course, to some extent upon the fineness of the lines of the dividing as well as upon the index line and the circumferential dimension of the scale, but in general it is not possible to estimate with certainty a scale reading to a closer accuracy than that corresponding to 0.01 inch of scale circumference (even when a vernier is employed) without magnification or other special means. This scale arc expressed as an angle $\delta\theta$ in degrees becomes

$$\delta\theta = \frac{0.01 \times 180}{\pi R_s} = \frac{0.573}{R_s}$$

where R_s is the radius of the scale in inches. The probable inaccuracy of scale reading at any point of the scale can therefore be expressed as

$$\delta\theta \cdot \frac{dC}{d\theta} \Big/ C$$

Expressed as a percentage this becomes

$$\frac{57.3}{R_s} \cdot \frac{1}{C} \cdot \frac{dC}{d\theta} \quad \ldots \quad \ldots \quad (1)$$

This *inaccuracy of reading* will, of course, vary throughout the scale in all condensers except those designed to have an exponential law. The actual *capacity inaccuracy* also varies somewhat throughout the scale, being usually somewhat smaller at higher capacities. The probable inaccuracy of scale reading should be of a lower order than that expected in the condenser itself.

Simple expressions for scale reading accuracy can readily be formed for condensers designed for any capacity law—expressions from which the correct scale radius for any given accuracy can be quickly found.

Linear Law Condenser (S.L.C.).

$$C_1 = a_1\theta + b_1$$

where

$$a_1 = \frac{\text{Max. cap.} - \text{Res. cap.}}{180}$$

and $b_1 = \text{Res. cap.}$

$$dC_1/d\theta = a_1$$

$\therefore$ from (1) the probable scale reading inaccuracy is

$$\frac{57.3a_1}{R_s(a_1\theta+b_1)} \quad \dots \quad \dots \quad (2)$$

The law constants a and b are always known during design whatever the condenser law, and so this and the following expressions for scale reading inaccuracy are very quickly evaluated.

Corrected Square Law Condenser (S.L.W.).

$$C_2 = (a_2\theta + b_2)^2$$

where

$$a_2 = \frac{\sqrt{\text{Max. cap.}} - \sqrt{\text{Res. cap.}}}{180}$$

and

$$b_2 = \sqrt{\text{Res. cap.}}$$

$$dC_2/d\theta = 2a^2\theta + 2ab$$

$\therefore$ from (1) the probable reading inaccuracy is given by

$$\frac{57.3\{2a_2(a_2\theta+b_2)\}}{R_s(a_2\theta+b_2)^2} = \frac{114.6a_2}{R_s(a_2\theta+b_2)} \quad (3)$$

Inverse Square Law Condenser (S.L.F.).

$$C_3 = (a_3\theta + b_3)^{-2}$$

where

$$a_3 = \frac{1}{180}\left\{\frac{1}{\sqrt{\text{Res. cap.}}} - b_3\right\}$$

and

$$b_3 = \frac{1}{\sqrt{\text{Max. cap.}}}$$

$$\frac{dC_3}{d\theta} = \frac{-2a_3}{(a_3\theta + b_3)^3}$$

the minus sign obtained when differentiating can be ignored and the probable reading inaccuracy is therefore—

$$\frac{57.3\,(2a_3)}{R_s(a_3\theta+b_3)^{-2}\,(a_3\theta+b_3)^3} = \frac{114.6a_3}{R_s(a_3\theta+b_3)} \quad (4)$$

Exponential Law Condenser (E.L.).

$$C_4 = a_4\epsilon^{b_4\theta}$$

where

$$a_4 = \text{Res. cap.}$$

and

$$b_4 = \frac{\log.\,(\text{Max. cap.}) - \log.\,(\text{Res. cap.})}{78.17}$$

$$\frac{dC_4}{d\theta} = a_4b_4\epsilon^{b_4\theta}$$

$\therefore$ the probable reading inaccuracy is

$$\frac{57.3\,a_4b_4\epsilon^{b_4\theta}}{R_s a_4\epsilon^{b_4\theta}} = \frac{57.3\,b_4}{R_s} \quad \dots \quad (5)$$

a constant quantity throughout the whole range since the condenser is designed to give a uniform percentage change of wavelength throughout its scale.

In Fig. 1 are plotted* the probable percentage scale reading inaccuracies for the four types of condensers having similar scale dimensions and capacity values, the ratio of maximum to minimum capacity being five to one.

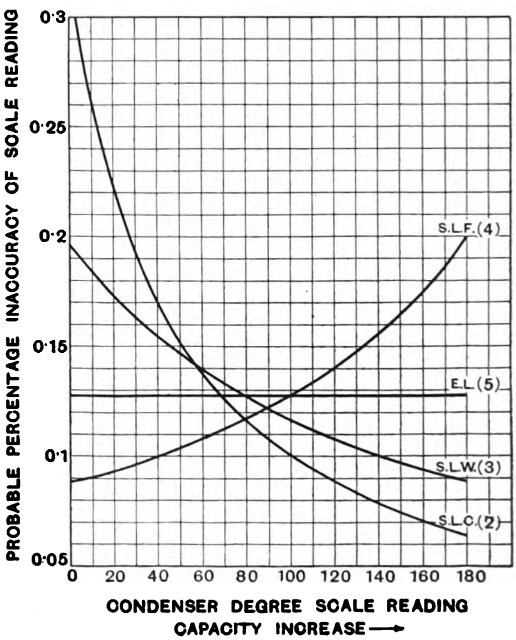


Fig. 1.

Capacity at 180 *degrees* $= 1000\mu\mu$F.
Capacity at 0 *degrees* $= 200\mu\mu$F.
Scale radius $= 4$ *inches.*

* The curve of the S.L.F. condenser has been reversed in order to make its capacity increase with an increase of scale reading to correspond to the curves of the other condensers.

It will be observed that the scale reading inaccuracy is inversely proportional to the actual capacity in the case of the ordinary S.L.C. condenser. In the case of the S.L.W. condenser, however, the scale reading is proportional to wavelength, which is, in turn, proportional to the square root of capacity; the scale reading inaccuracy, therefore, being, of course, inversely proportional to wavelength, is inversely proportional to the root of the capacity.

In the S.L.F. condenser the scale reading is proportional to frequency, which is, in turn, inversely proportional to the square root of capacity; the scale reading inaccuracy therefore, being inversely proportional to frequency, is proportional to the root of capacity.

It follows, therefore, that the *variation* of scale reading accuracy throughout the scale will be less in S.L.W. and S.L.F. condensers than in those having a linear capacity law, this advantage becoming, of course, more appreciable as the capacity range of the condenser is increased, as is shown in the curves of Fig. 2 for condensers of 13.9 to 1 capacity ratio.

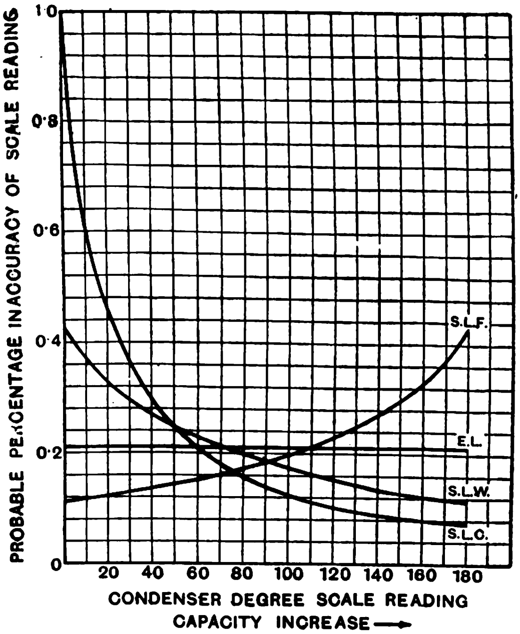


Fig. 2.

Capacity at 180 *degrees* = 1000$\mu\mu$F.
Capacity at 0 *degrees* = 72$\mu\mu$F.
Scale radius = 4 *inches.*

Atmospherics and Transatlantic Telephony.

A New Directional Polar Curve.

I.E.E. Wireless Section, Chairman's Address.

THE opening meeting for the session of the Wireless Section of the Institution of Electrical Engineers was held on Wednesday, 2nd November, the chair being taken by the Institution President, Mr. A. Page.

A very cordial vote of thanks to the retiring Section Chairman (Prof. C. L. Fortescue) for his services during the previous session was moved by Major B. Binyon, seconded by Dr. R. V. Hansford, and carried with acclamation. The President then called upon the new Chairman of the Wireless Section, Lt.-Col. A. G. Lee, M.C., B.Sc., to deliver his inaugural address.

The address dealt with the problem of atmospherics, more particularly in connection with Transatlantic telephony, the lecturer reviewing the matter generally, and discussing directional methods of minimising the effect of atmospherics. In connection with these methods a novel method of direction finding giving a very sharp polar curve for a combination of single frame and vertical aerial was described.

When the Wireless Section was started in 1920, said the Chairman, much of the matter dealt with referred to war-time research and development, which, for various reasons, had not been previously published. Since then there had been a lag between research and the publication of results, but the supply of papers for the new session was good. He also referred to the small number of papers dealing with broadcasting, although the informal discussions on this subject held during the last session had been very successful.

The important wireless matters of the past year had been beam working, and Transatlantic telephony, but instead of dealing with general aspects of these, he proposed to confine himself to one question. This was the problem of atmospherics,

and the practical illustrations he proposed to take from their experience on the Transatlantic telephony working.

Useful information on the wave form of atmospherics had been given by Appleton, Watson Watt

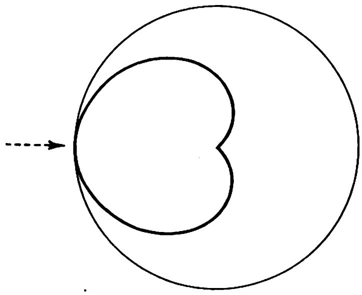


Fig. 1.

and Herd. This showed that the atmospherics were generally of an aperiodic or quasi-periodic form of about .003 second mean duration, and .1 volt per metre mean field strength. This was much greater than average signal strength. The work had also shown the existence of ripples on the main waveform.

Examination of the distribution in azimuth had been made by the cathode ray direction finding system described by Watson Watt and Herd, where two loop aerials were used at right angles and their

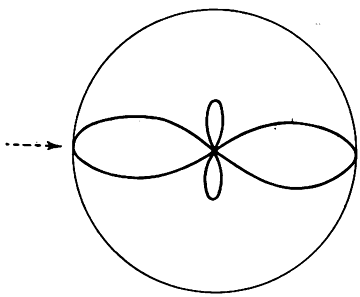


Fig. 2.

voltage applied to the plates of a cathode ray oscillograph. Observations with this apparatus had been made during the past summer at Cupar, Fifeshire, the Post Office receiving station for the Transatlantic service. A slide was shown giving the results obtained in the form of a target diagram, using the direction of the American signal as zero. The most prominent disturbance was at about 200 degrees to this zero. Simultaneous observations between Cupar and Slough, with the two points connected by telephone line, had shown that these sources were mostly in Germany, Latvia, Russia and farther away, also that this portion of Europe had been much disturbed during this summer.

Before selecting Cupar as the site for the reception of the Transatlantic telephony observations of signal/atmospheric ratio had been made at various places in England and Scotland. Going North, the signal was generally stronger and the atmospherics less. At Cupar the ratio of signal to atmospherics was four times that at Wroughton, Wiltshire, while at Thurso it was eight times.

Another type of atmospherics trouble was due to rainstorms. When signals were weak, electrified rain produced a hissing sound, sometimes sufficient to put the circuit out of action. It was hoped that large frames suitably spaced would effect an improvement in this respect.

The lecturer next turned to the spectrum of atmospherics. Lord Rayleigh had shown that an aperiodic pulse was capable of being analysed into

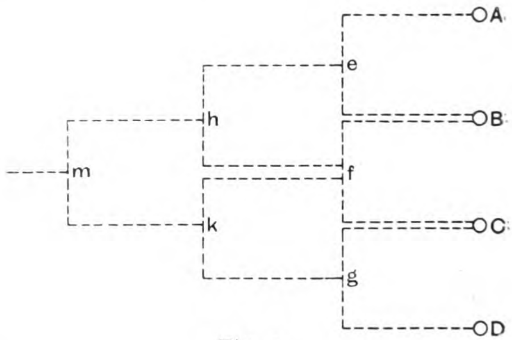


Fig. 3.

a continuous spectrum of a Fourier series of sinusoidal components. Atmospherics thus contained all frequencies. If a receiving circuit admitted a certain band, it admitted atmospheric frequencies in that band, and it was impossible to exclude them by an increase of selectivity.

As regards the possibility of effects from the ripples mentioned, there was no evidence that effects were more pronounced at one frequency. The change in spectrum was smooth, although the spectrum did change with different times of day.

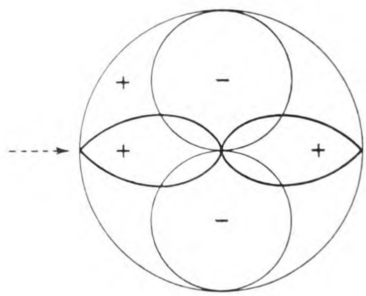


Fig. 4.

This was no doubt due to differences of attenuation by day and night.

Extensive measurements had been made for several years before the Transatlantic circuit was opened, on a band of 2,500 cycles wide. It was

concluded that a wavelength between 5,000 and 6,000 metres was optimum for Transatlantic working.

The receiver must admit a band sufficient for intelligibility and further reduction of the band width for the exclusion of atmospherics would only reduce intelligibility. The Transatlantic circuit used a single side band of frequencies corresponding to the voice frequencies of 400 to 2,800 cycles. This was found sufficient for intelligibility, although not for complete naturalness. Considerable energy would be required for the transmission of the voice frequencies below 400, while the narrow band used limited the exposure to atmospherics.

The lecturer then proceeded to a brief description of the Post Office receiver used at Cupar. It employed single detection, as compared to the American receiver where double detection was used. Filtering at high frequencies was difficult, and the final narrowing of the band was done by low frequency filtering.

Slides were shown of the low pass and high pass filters, and of attenuation curves for the filters and for the complete receiver.

After a narrow band the only other method was directive reception, which he then proceeded to discuss.

Experiments on wave antennæ had shown this type of antenna to be suitable, and it had been adopted for use at Cupar. The wave antenna picks up the horizontal field which is weak at the near end, increasing towards the farther end, where it is transformed and transmitted to the receiver by transmission lines. Its properties depend on tilt to give a horizontal component; and the tilts at Chedzoy (Somerset), Wroughton and Cupar had been found to be .1, .7 and 1 degree respectively, as against the 2 or 3 degrees found in America. This was presumably due to differences in the soils. A slide showed directional curves of a wave antenna, three curves being given, *A* for the effect with no vertical, *B* for the calculated effect as it existed, and *C* for the same with methods of compensation for vertical. Slight differences existed between the three limbs of the wave antenna, due to differences in the ground. This had the disadvantage of giving bad combination when desired for more directive reception.

The lecturer then turned to a discussion of various systems of spaced antenna to obtain highly directive antenna arrays. The beam system was an example of the effect of suitably spaced antenna.

Two cases were illustrated by slides. The first was of two vertical aerials spaced one quarter of a wavelength apart in the line of transmission, with 90 degrees phase difference. This gives a cardioid polar diagram as in Fig. 1. The other case was that of two vertical aerials spaced 0.6 of a wavelength apart broadside on to the line of transmission with 0 degree phase difference. This gives a polar curve of a long, narrow figure-of-eight in the line of transmission, with a short, narrow figure-of-eight at right angles, as in Fig. 2.

A pyramid combination of antennæ could be arranged as in Fig 3, to give any combination, taking advantage of the separate properties of *A*, *B*, *C*, and *D*, then of their combinations into *e*, *f*, and *g*, and so forth. Directional curves (on Cartesian co-ordinates) were shown for various antenna arrays, and their properties briefly discussed by the lecturer.

Col. Lee then proceeded to describe a new system of frame and vertical aerial combination to give the polar curve shown in Fig. 4, to which he gave the name of "the leaf-shaped diagram."

The combination of frame and vertical aerials was already known in the usual arrangement to give a heart-shaped diagram, which resulted from the change of sign between the two loops of the figure-of-eight diagram due to reversal of phase. If the same phase was preserved in each loop of the figure-of-eight diagram, the effects could be regarded as showing each loop as of negative sign, while the non-directional circle diagram was shown as positive (as is shown in Fig. 4). The combination gave the narrow leaf-shaped polar diagram shown in heavy lines.

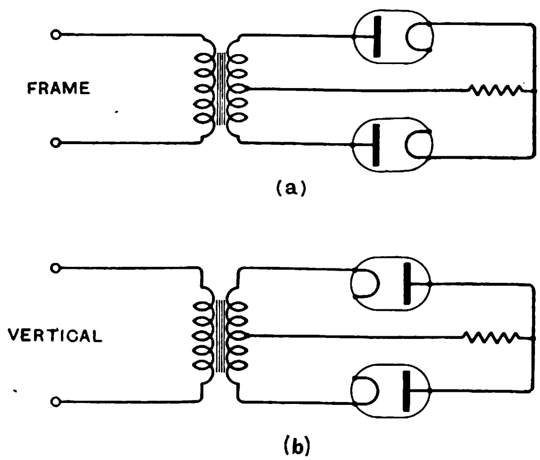


Fig. 5.

The similarity of phase in the two loops of the figure-of-eight diagram could be obtained, for example, by an arrangement of full wave rectification, as shown in skeleton in Fig. 5.

A final directional curve (or Cartesian co-ordinates) was shown for a triple broadside array of leaf-shaped diagrams, giving a very striking directive effect.

The lecturer concluded by expressing the view that directional reception provided the only means of defence against atmospherics. For long waves and long distances, atmospherics and signals arrive from a horizontal direction. Only the atmospherics from near thunderstorms arrived from vertical directions, and in this country these were not numerous and much less disturbing.

At the conclusion of his address a vote of thanks to the new Chairman was carried with acclamation on the motion of the President.

Book Reviews.

TRANSFORMATOREN - VERSTÄRKER (Transformer-Amplifiers). By Müller and von Ardenne. 137 pp. and 66 Figs. R. C. Schmidt & Co., Berlin. 4M.

This forms Vol. 22 of the " Radio-Reihe " issued by these publishers, and is a companion volume to von Ardenne's book on Resistance Amplifiers which formed Vol. 17 of the series. The book is divided into four parts. In the first part the three-electrode valve is explained and its characteristics derived and discussed; the second part deals with the iron-cored transformer, the effects of capacity, iron loss, and superposed direct current, etc., the resonant frequencies and the ratio, methods of measuring and analysing the performance of transformers. Stress is laid on a point which is often overlooked, viz., the importance of taking the direct anode current into account in designing the iron core of the transformer. The authors give $H=3$ as the maximum allowable value of the steady magnetising force. The third section deals with the problem of the valve and the transformer combined and the desirable characteristics of each in order that the combination may give a maximum amplification with a minimum of distortion. The concluding section describes a few actual amplifiers of which diagrams and photographs are given. The book can be thoroughly recommended to those interested in the subject.

G.W.O.H.

FASCHENBUCH DER DRAHTLOSEN TELEGRAPHIE UND TELEPHONIE. Edited by Dr. F. Banneitz. xvi. + 1,253 pp. with 1,190 Figs. and 131 Tables. Julius Springer, Berlin. Price 64.5M.

Although called a pocket-book, this is not a book that one would care to carry in his pocket; it is rather a reference book to keep on one's desk and use on every possible occasion. It is a wonderfully complete compendium of radio telegraphy and telephony written by a large number of German experts; it deals in an authoritative manner with all the latest developments of the subject, naturally in a condensed form, but giving the essentials and plentiful references to original papers for those who require further information. It contains also a section on mathematical tables and formulæ, with brief descriptions of graphical and symbolic methods; an English-German and a French-German technical dictionary—in fact, it contains everything that a radio engineer could possibly want to know, and there is no need to enumerate the contents. We have only found one flaw, and that is the omission to give *E.W. & W.E.* among the list of radio magazines published in various countries. We can unreservedly recommend this book to those who have any knowledge of German. It costs over three guineas, but is worth it.

G.W.O.H.

DIE ELEKTRONENRÖHRE (Thermionic valves). By Forstmann and Schramm. 239 pp. with 197 Figs. Published by R. C. Schmidt & Co., Berlin. Price 9.50M.

This is Vol. 24 of the series " Radio-Reihe " issued by this publisher. It is subdivided into three parts: the theory of the valve, valve circuits, and practical applications. A section deals with valve manufacture but, generally speaking, the book deals with theory and deals with it in a very clear and logical way, the treatment of audio-frequency amplification being very thorough and yet easily followed. The references are almost entirely to German work, the authors being either unaware of the work done in other countries or regarding it as of little interest to their readers. We were surprised to see that Prof. Zenneck's name was misspelt in the only two places we noticed it. The use of the valve as a generator of oscillations is not considered, nor is its application to heterodyne reception, the scope being indicated on the title page by the sub-title " Its theory and application in receiver and amplifying circuits.' It is a book which can be unreservedly recommended to anyone with the necessary knowledge of German.

G.W.O.H.

Correspondence.

Amplification of Small Currents.

To the Editor, E.W. & W.E.

SIR,—I read with interest Mr. Wilson's letter with reference to my article " The Amplification of Small Currents by Means of the Thermo-Relay, etc." I regret that I was unaware of Mr. Wilson's work in this particular direction, but it is naturally quite outside my scope to deal with a question of priority. Nevertheless, I shall see that the letter comes to the observation of Prof. Moll and Dr. Burger.

It is possible, though on this point I am not certain, that the principle of the method is old. There is, however, a very real difference between such methods as given by Mr. Wilson and those of Moll and Burger. The latter use the thermo-relay, and this is really the whole secret of the success of the method. This relay, constructed of thin thermo-foil of small heat capacity and mounted in vacuum, is a precise and reliable instrument, and even if this were all that Moll and Burger had done, it would be a tremendous advance on previous methods.

I might also point out that the article dealt with the method " by means of the thermo-relay," so that I may be excused, by definition, of dealing with less satisfactory methods of small current amplification.

Cambridge. JAMES TAYLOR.

Abstracts and References.

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PROPAGATION OF WAVES.

THE CORRELATION OF RADIO RECEPTION WITH SOLAR ACTIVITY AND TERRESTRIAL MAGNETISM—II.—G. W. Pickard. (*Proc. Inst. Radio Engineers*, 15, 9, pp. 749-766, September, 1927.)

The following summary is given: The solar, magnetic and reception data from the author's recent paper on this subject are now compared by periodic means, and clearer pictures of their inter-relations are given. The solar rotation period and its second, third, and fourth harmonics (27.3, 13.6, 9.1 and 6.8 days) are found for all three elements, the general relation being that sunspots on the solar meridian coincide with disturbances of terrestrial magnetism, lowered night reception and higher day reception. Night static at 1,330 kilocycles is found inversely related to night signal reception at the same frequency and therefore directly correlated with sunspots. Day static at 15-25 kilocycles is also, although less definitely, inversely related to the day signal at the same frequency, and therefore in general inversely correlated with sunspots. Periodic means of eight years of day reception show a marked double frequency annual component, with maxima near the vernal and autumnal equinoxes closely paralleling the well-known annual variation in terrestrial magnetism. Tables of daily sunspot numbers for 20 degrees and 40 degrees central zones are given for 1926, and night reception values for WBBM are continued from the former paper to 31st March, 1927.

LONG-WAVE RADIO MEASUREMENTS AT THE BUREAU OF STANDARDS IN 1926, WITH SOME COMPARISONS OF SOLAR ACTIVITY AND RADIO PHENOMENA.—L. W. Austin. (*Proc. Inst. Radio Engineers*, 15, 10, pp. 825-836, October, 1927.)

A summary of the measurements made by the Bureau of Standards on long-wave signal intensities and atmospheric disturbances during 1926, together with some measurements from former years, for the purpose of studying the relations of radio transmission and atmospheric disturbances to other natural phenomena.

The observations show with considerable certainty that there is a general increase of signal strength with increasing sunspot numbers; there also appears to be a possible periodic relationship between the sunspot numbers and daylight signals, in which, in the case of most stations observed, the signals are nearly in opposite phase to the periodic changes of the sunspots. This is in agreement with the results of Pickard in the broadcasting range. With regard to long-wave daylight atmospherics, a comparison of the monthly averages of sunspots, covering several years, shows little certain correlation between the two.

It is stated that a limited number of mimeographed copies of the Bureau of Standards record of daily signal measurements of long-wave stations since 1st January, 1924, are available for distribution to those engaged in the study of radio transmission phenomena.

ZUR BERECHNUNG DES ROTATIONSSYMMETRISCHEN STRAHLUNGSFELDES (Calculation of the radiation field of rotational symmetry).—M. Willstätter. (*Annalen der Physik*, 84, 1, pp. 163-166.)

Last year in these Annalen (80, 7, pp. 728-740; these abstracts, January, 1927, p. 49), Kiebitz published a paper calculating the propagation of the waves of wireless telegraphy. On the simplifying hypothesis that the resultant electric force E at any point in space is equal in magnitude to the magnetic field strength H, as with plane waves, he obtained from Maxwell's equations, by integrating after the method of characteristics, a solution of remarkable simplicity, firstly quite generally and then for the particular case of propagation around the globe. However, a strict solution of the problem, as is well known, leads to a complicated series development with Bessel and spherical functions. At the suggestion and with the support of Prof. Sommerfeld the author has closely examined Kiebitz' results: without going into the general case, even the simplest case of the Hertzian oscillator shows that Kiebitz' methods lead to incorrect results, as is set out here.

The conclusion is reached that while Kiebitz' methods of calculation are mathematically correct, the statement of the problem in no way corresponds to the physical conditions of wireless telegraphy, particularly the requirement that the solution must be finite everywhere, besides at the source (transmitter). (*Cf. L'Onde Electrique*, December, 1926, and March, 1927; these abstracts, July, 1927, p. 441).

CONSIDERAZIONI SULLA PROPAGAZIONE DELLE ONDE ELETTROMAGNETICHE (Discussion of the propagation of electromagnetic waves).—G. Pession. (*L'Elettrotecnica*, 14, 27, pp. 666-682.)

The author surveys the work that has been done on wave propagation and forms the opinion that the only waves really interesting at present for long distance communication are those below 100 metres, medium waves being kept for comparatively short distances.

WAVELENGTH CHANGES.—TIDAL INFLUENCE. (*Electrical Review*, 21st October, 1927, p. 701.)

Variations of the transmitter frequency of station WCGU, at Sea Gate, Coney Island, U.S.A., are due to the rise and fall of the tides, according to the

chief engineer of the station. Tests with a laboratory oscillator showed that during ebb tide the wavelength decreased and then, as flood tide approached, increased to more than the wavelength prescribed for the station. The aerials are 75 ft. from the breakers, and the sand, when wet, becoming an excellent conductor of high-frequency current, adds capacity to the antenna while reducing its effective height. The operators are obliged constantly to check the wavelength of the station.

ATMOSPHERICS AND ATMOSPHERIC ELECTRICITY.

Radio Atmospheric Disturbances and Solar Activity.—L. W. Austin. (*Proc. Inst. Radio Engineers*, 15, 10, pp. 837-842, October, 1927.)

Various graphs of observations are shown, from which the conclusion is drawn, that while there appears to be some evidence of solar influence on long-wave daylight atmospheric disturbances, at present it is insufficient to establish any connection with certainty. It may be that the influence of solar activity on the weather and that of the weather on atmospherics is the indirect path by which the connection must be traced.

Two Contrasting Examples wherein Radio Reception was affected by a Meteorological Condition.—E. H. Kincaid. (*Proc. Inst. Radio Engineers*, 15, 10, pp. 843-868, October, 1927.)

This paper is intended primarily to show that static has sufficiently definite relationship to the distribution of the atmosphere as plotted on the daily weather map to enable one by proper observations to make use of static in weather forecasting, and to make use of our present knowledge of atmospheric distribution and movement in static forecasting. The "two contrasting examples" are, that on one occasion, static was terrific and the observer was within the 29.60 isobar, south-east quadrant of a hurricane, and on the other occasion, the observer was within a homogeneous High and static was practically nil. Some observations of others who have studied this subject are reproduced.

Loi de Distribution des Orages Magnétiques et de leurs Eléments. Conséquences à en tirer sur la Constitution du Soleil (Law of distribution of magnetic storms and their elements. Inferences to be drawn regarding the composition of the sun.)—H. Deslandres. (*Comptes Rendus*, 185, 14, 3rd October, 1927, pp. 626-630.)

A third article on this subject (see *Comptes Rendus*, 183 and 185, pp. 1313 and 10 respectively; these abstracts, September, 1927, p. 572). The daily variation of the magnetic needle is attributed to the ultra-violet and X radiations and also in part to the corpuscular radiation emanating from the whole solar disc, but actual magnetic storms come either directly or indirectly from the permanent volcanoes in the deep rotating layer. Spots are secondary emission centres and it is explained why magnetic storms are not always in agreement with them.

PROPERTIES OF CIRCUITS.

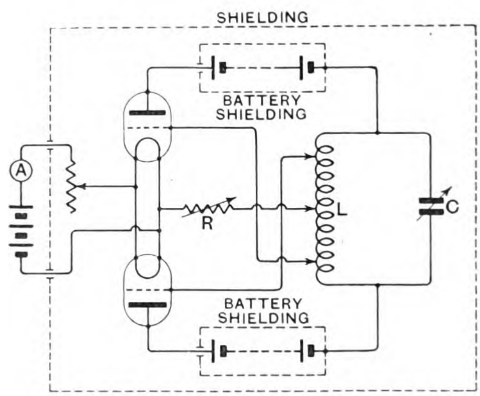
The Testing of Audio-Frequency Transformer-Coupled Amplifiers. — H. Diamond and J. Webb. (*Proc. Inst. Radio Engineers*, 15, 9, pp. 767-791, September, 1927.)

The performance of an audio-frequency transformer-coupled amplifier is considerably affected by the reaction load across the coupling-transformer secondary due to the impedance in the plate circuit of the valve following the transformer. This paper discusses the effect of such reaction, and four methods of test are described whereby the actual performance of a given amplifier may be measured under any condition of loading (due to reaction).

The first two methods of test are essentially bridge circuits in which the amplifier output E.M.F. is balanced against an auxiliary voltage, the magnitude and phase relationship of which (relative to the amplifier input voltage) is determinable. In the third method, the second amplifier valve serves both for loading and for balancing, the auxiliary balancing valve being omitted. The fourth test method is oscillographic.

A Constant Frequency Oscillator and its Oscillation Frequency.—H. Nukiyama and K. Nagai. (*Proc. Imperial Academy Japan*, 3, 7, pp. 430-433.)

In order to keep the frequency change in the oscillation current of a valve oscillator as small as possible, Messrs. Matsudaira and Nukiyama have suggested the arrangement shown below.



The two sets of plate battery are introduced in the plate circuit of each valve separately so that the impedance of the grid circuit is small and the average grid voltage can be kept at the right value. The resistance R introduced between the filament and the oscillation circuit will give an increasing bias when the amplitude of oscillation increases. If the value of R is properly chosen, the frequency of oscillation is almost independent of the filament current within a wide range. Since in this condition the valve may not give out reactive power, investigation was made as to whether the frequency of oscillation is not equal to the resonance frequency of the oscillation circuit.

From the experiments it was concluded that when a valve oscillator has a character of constant frequency, the frequency of oscillation itself is a particular frequency, *i.e.*, the resonance frequency. This fact furnishes ground for stating that a constant frequency oscillator can reasonably be used as a permanent standard of frequency.

The Alteration of Resistance, Inductance and Capacity by means of Resistance-coupled Amplifiers.—C. Aiken. (*J. Opt. Soc. Amer. and Rev. Sci. Instr.*, 15, 2, pp. 85-95.)

Various schemes for altering the effective resistance, inductance and capacity of a circuit employing a resistance-coupled amplifier are discussed. The possibility is shown of multiplying the reactance of a circuit by a large factor which may be made either positive or negative. Thus the reactance of a circuit can be neutralised for all frequencies. Resistance reducing schemes may be divided into two classes: (1) those which are independent of frequency, suitable for the reduction of large resistances to a relatively small value; and (2) those which are fairly insensitive to small frequency changes and are suitable for the annulment of small resistances.

Die Berechnung des Anodenstromes und der Verstärkungszahl bei Widerstandsverstärkern (Calculation of the anode current and amplification factor in resistance amplifiers).—W. Bermbach. (*E.N.T.*, 48, 22, pp. 757-759.)

With negative grid tension, the anode current can be calculated with the help of the space charge formula. This is reduced to a simple cubic equation by suitable transformation and the introduction of a new unknown. From calculation work curves are plotted from which data on the amplification factor can be obtained. The influence exerted by the different constants on the amplification is shown by means of examples.

Die Berechnung der Scheinkapazität bei Widerstandsverstärkern (Calculation of the apparent capacity in resistance amplifiers.)—M. von Ardenne and W. Stoff. (*Zeitschr. für Hochfrequenz.*, 30, 3, pp. 86-89.)

A formula for the calculation of the apparent capacity of an amplifier stage with any anode load is derived, in which the phase displacement between E_a and E_g must be taken into account. The reaction of the anode load on the grid circuit in the case of the individual stages of a threefold low frequency amplifier with resistance coupling is shown by means of a numerical example. It is to be noted here, that in consequence of this reaction, besides an additional capacity, an additional ohmic resistance must be assumed in the grid circuit. The calculation further shows that in the case of the three-fold amplifier mentioned, only the first stage possesses any perceptible frequency relation.

Resonance in Series and Parallel Circuits.—H. J. Boyland. (*E.W. & W.E.*, November, 1927, pp. 675-683.)

Note on Detection by Grid Condenser and Leak.—W. van B. Roberts. (*Proc. Inst. Radio Engineers*, 15, 9, pp. 793-796, September, 1927.)

It has been said that detection by the ordinary grid-condenser and leak gives poor quality (*i.e.*, low audio-frequencies favoured at the expense of the higher ones) unless an undesirably small condenser or low leak resistance is used. This paper attempts to show as simply as possible, that actually, good quality can be obtained even when using as large a grid condenser as desirable, because the resistance which determines the relative loss of high frequencies is not the resistance of the grid-leak alone, but the resistance of the grid-leak and grid-filament resistance of the valve in parallel. Under usual operating conditions the latter is so low that loss of quality is very slight. The resistance of the grid-leak is important chiefly in determining the grid-filament resistance of the valve, and need not be low itself.

TRANSMISSION.

Abhangigkeit der An- und Abschwingvorgänge des Röhrensenders von den Betriebs-Bedingungen (Dependence of the phenomena of growth and decay of oscillation in the valve transmitter upon the working conditions).—W. S. Pforte. (*Zeitschr. für Hochfrequenz.*, 30, 3, pp. 83-86.)

A paper dealing with the dynamic processes of modulation, with the phenomena of growth and decay of oscillations. By means of a large series of oscillographic records and their evaluation, the dependence of these phenomena upon the different transmitter elements of the heating, grid and anode circuits is considered. The significance of these phenomena for high-speed telegraphy and telephony is pointed out.

Die Telefunken-Rundfunksender in Deutschland (Telefunken broadcast transmitters in Germany).—W. Meyer. (*Telefunken-Zeitung*, 45/46, pp. 11-38.)

A map is shown giving the geographical position of German broadcast transmitters, which appear to number 27, 21 of which were constructed by the Telefunken Company. Maps are also given indicating the ranges of these stations for crystal and one- and three-valve receivers. The Telefunken transmitters are of seven different types, each of which is described. The article is profusely illustrated.

RECEPTION.

The Screened Valve in L.F. Circuits.—N. W. McLachlan. (*Wireless World*, 19th and 26th October, 1927, pp. 536 and 577 respectively.)

Some Notes on the Effect of Coupling between Loop and Beating Oscillator Circuits in a Superheterodyne Receiver.—E. Ullrich and A. Reeves. (*E.W. & W.E.*, November, 1927, pp. 652-656.)

H.F. Amplification on Short Waves.—F. Charman. (*Wireless World*, 12th October, 1927, pp. 519-523.)

Description of a practical three-valve receiver with one H.F. stage.

Über [Empfangsbeobachtungen bei Gleichwellenrundfunk (Observations on the reception of broadcast transmissions of the same wavelength).—F. Eppen. (*Elekt. Nachr. Technik*, 4, 9, pp. 385-387.)

The endeavour to bring broadcast reception within the reach of as many listeners as possible —and that with the simplest means—leads to the erection of ever more transmitters. Since, for financial reasons, many of these transmitters are unable to offer their own programmes, but act as intermediate transmitters, conveying the programme of a principal transmitter, the attempt was made to discover whether one could not have several transmitters, for instance, all the intermediate transmitters of a principal transmitter, working on the same wave. This would have the advantage of many fewer waves being necessary and so the individual transmitters would have greater freedom from disturbance.

The investigation showed that, at many places, undistorted reception is not to be attained, owing to interference between the carrier frequencies, but that if for those regions a transmitter working on another wave can be provided, the advantages of broadcast transmissions of the same wavelength are undoubtedly realisable.

Un Perfectionnement Intéressant d'un Montage Bien Connu (An interesting improvement of a well-known circuit-arrangement.) —H. de Joubert. (*Radio-Revue*, October, 1927, pp. 467-8.)

Description of a four-valve receiver in which the reaction coil does not start from the plate of the detecting valve, as is usual, but from that of the high-frequency valve, the advantages of which are enumerated.

Die Entwicklung von Rundfunkempfängern (The development of broadcast receivers.) Dr. Ewald. (*Telefunken-Zeitung*, 45/46, pp. 49-54.)

Receiver with over 2,000 Listening Points.— (*Wireless World*, 26th October, 1927, pp. 575-576.)

Description of an automatically controlled installation, without batteries, capable of working 2,000 pairs of headphones and 80 loud-speakers simultaneously.

Über moderne Musik- und Sprachübertragungsanlagen (Modern means of conveying music and speech).—Dr. Kühn. (*Elekt. Nachr. Technik*, 4, 9, pp. 391-396.)

Communication from the amplifier department, Siemens and Halske, discussing systems of microphone, amplifying apparatus and loud-speaker, for supplying, say, a hospital or hotel.

Theory of Receiving Aerials.—F. M. Colebrook. (*E.W. & W.E.*, November, 1927, pp. 657-666.)

Receiver for the Sudan Government. (*Electrician*, 28th October, 1927, p. 548.)

Brief description of a portable set for waves of 15-150 metres for receiving short-wave time signals from the principal stations of the world, and also for the checking of chronometers. There are only two valves—one detector with reaction, and one low frequency. The aerial is semi-aperiodic, with a tuned grid, and comprises a surveyor's tripod on which a vertical rod is mounted, arranged in four sections, the complete aerial with its earth mat fitting into a leather carrying case.

Further Investigation of Synthetic Galena Detectors and a New Theory of Crystal Rectifiers.—W. Ogawa, C. Nemoto and S. Kaneko. (*Researches of the Electrotechnical Laboratory*, Japan, 1927.)

The various metallic sulphides are investigated and no definite relation is found between sensitivity and composition. After a review of the various theories, known as electrolytic, electrothermal, and electronic unilateral conduction, the authors propose that the electron-emitting faculty of the surface layer of each electrode and the electron receiving faculty of each electrode be the main basis for discussion. They conclude that to obtain good rectification the difference of the electronic characteristics of the electrodes must be as large as possible, that the resistance of the electrode must be great enough to minimise metallic conductivity, but must not be so great as to retard the passage of electrons, especially at the anode, and that the contact pressure and area must be small enough to minimise metallic conductivity. With a soft crystal a light contact is necessary.

VALVES AND THERMIONICS.

Über Arbeitskennlinien und die Bestimmung des güngstigsten Durchgriffes von Verstärkerröhren (On working characteristics and the determination of the optimum "Durchgriff" ($1/\mu$) of amplifying valves.— A. Forstmann and E. Schramm. (*Zeitschrift für Hochfrequenz.*, 30, 3, pp. 89-95.)

Equations for the working characteristics of a valve are derived when the plate circuit is loaded with a real and a complex resistance. From these equations a method is given by which, taking account of the conditions for rectilinearity and the limiting value for the internal valve resistance, the most favourable "Durchgriff" ($1/\mu$) can be found.

The Performance of Valves in Parallel.— R. P. Denman. (*E.W. & W.E.*, November, 1927, pp. 669-674.)

Space Charge as a Cause of Negative Resistance in a Triode and its Bearing on Short Wave Generation. — L. Tonks. (*Physical Review*, 30, 4, pp. 501-511.)

The mathematical theory of negative resistance in both plate and grid circuit of a triode is worked out. Negative resistance is found when a virtual cathode is formed between grid and plate. In general this requires a plate voltage low compared with the grid voltage, a minimum electron current density depending upon the voltages used, and proper electrode spacing. For plane parallel construction the plate-grid distance must exceed the grid-cathode distance and for cylindrical construction the ratio of plate to grid diamete

must exceed 2.15. Typical theoretical plate and grid characteristics are plotted. Failure of the experimental verification of these static characteristics through the occurrence of oscillations is not unexpected in view of the short relaxation time of the triode. When this theory, in combination with that proposed by Gill and Morrell, is applied to the short-wave oscillations discovered by Barkhausen and Kurz, their main features are explained.

X-Rays and Radio Valves.—J. Taylor. (*E.W. & W.E.*, November, 1927, pp. 666-668.)

Les Lampes Spéciales et leur Utilisation (Special valves and how they are used).—R. Leclère. (*Radio-Revue*, October, 1927, pp. 464-465.)

A brief discussion of valves with one grid and two plates, with one plate and two grids, and with two grids and two plates.

The Characteristics of Tungsten Filaments as Functions of Temperature. Part III.—H. Jones and I. Langmuir. (*General Electric Review*, August, 1927, pp. 408-412.)

Concluding part of an article, the first two parts of which appeared in the June and July numbers of the *Review*, giving the most recent data on the characteristics of tungsten filaments at various temperatures.

Apparat zur selbsttätigen Aufzeichnung der Röhrencharakteristik (Instrument for plotting valve characteristics automatically). (*E.T.Z.*, 48, 36, p. 1,192.)

A Device to draw Valve Characteristic Curves Automatically.—G. Campbell and G. Willard. (*J. Opt. Soc. Amer. and Rev. Sci. Instr.*, 15, 1, pp. 53-55.)

Plate-current is plotted against grid-potential. To make the ordinate represent plate-current, a known resistance of suitable magnitude is put in the plate circuit across which an L and N recording pyrometer is connected, thus recording the potential drop across the resistance which is directly proportional to the current. To make the abscissa represent grid-potential, the roll of co-ordinate paper is rotated uniformly with the variation of the grid-potential, which is effected by operating both the paper roll and the grid-potential potentiometer by the same motor though speed reducing gears.

The Theory and Characteristics of Radiotrons.—L. Koller and H. Schroeder. (*General Electric Review*, August and September, 1927, pp. 400 and 453, respectively.)

An elementary article on valves, intended to give a complete account of fundamental theory and supply a logical and up-to-date assembly of the related facts.

DIRECTIONAL WIRELESS.

The Round Island Radio Beacon. (*Electrical Review*, 7th October, 1927, p. 600.)

Illustrated description of the new wireless station for the assistance of navigation at sea, installed by the Marconi Company for Trinity House.

Berechnung von Richtstrahl-Antennen (Calculation of directional-beam antennæ).—H. Plendl. (*Zeitschr. für Hochfrequenz.*, 30, 3, pp. 80-82.)

Radiation equations and diagrams are given for

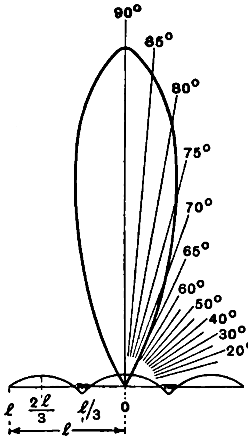


Fig. 2.

the horizontal antennæ described above, which are caused to radiate in the same phase by means of phase reversal coils. In order to show how the radiation differs when the phase is like and unlike,

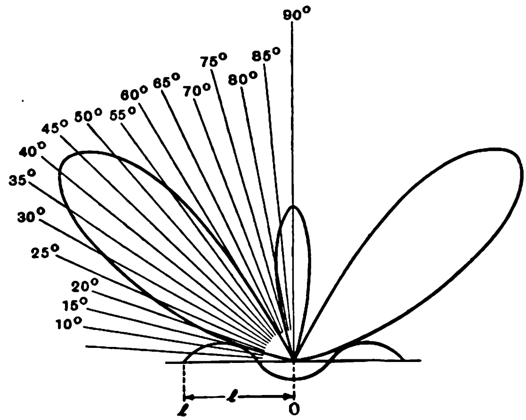


Fig. 3.

the polar curves in the two cases are drawn for comparison for an antenna three half-waves in length.

In Fig. 2 the phase is like, and in Fig. 3 unlike.

Das Rückstrahlfeld einer Hochantenne und seine Abhängigkeit von der Frequenz (The re-radiated field of an elevated antenna and its dependence on the frequency).—F. A. Fischer. (*E.T.Z.*, 48, 12, 1927, pp. 396-397.)

The re-radiated field of an elevated antenna can be split up into two components, one in phase with

the incoming wave and the other at 90 degrees to it. The first produces a quadrantal directional error, and the second a blurring of the signal minimum and requires an auxiliary antenna for its compensation. The behaviour of these components is discussed in relation to the mistuning of the elevated antenna from the frequency of the incoming waves. When the antenna is distuned, the second effect is present, but when tuned, only the former is present, producing a deviation with sharp minima.

RICHTSTRAHLUNG MIT HORIZONTALEN ANTENNEN (Directional radiation with horizontal antennæ).—A. Meissner. (*Zeitschr. für Hochfrequenz.*, 30, 3, pp. 77-79, September, 1927.)

Continuation of the author's experiments with horizontal antennæ and reflectors, described in

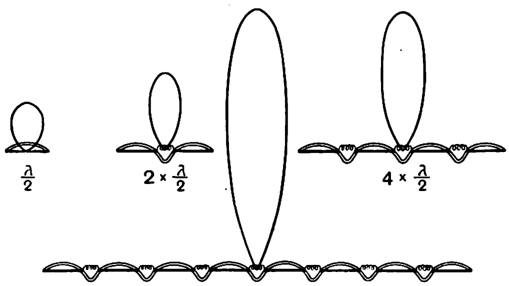


Fig. 1.

this *Zeitschrift* for September last year (these Abstracts, November, 1926, p. 699). It is found that the energy radiated by a transmitter can be concentrated in a horizontal circle by combining several horizontal antennæ oscillating in the same phase, as shown in Fig. 1, and in a vertical circle, by arranging a parabolic reflector around these antennæ, as represented in Fig. 2.

For a beam concentrated in this way, determination was made of the most favourable angle of

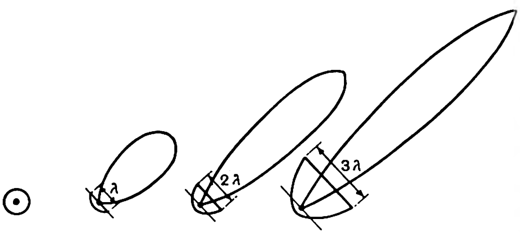


Fig. 2.

radiation at the transmitter. In order to minimise the dimensions and cost, the smallest possible wave was employed, namely that of 11 metres, thus below the limit of the wave-range within which reception over 10,000 km. (South America) was to be expected, according to theory (Taylor and Hulbert, *Phys. Rev.*, 27, 189, 1926), which indicated that the radiation would be bent away from the earth at such high frequencies. The experiments showed not only that a wave of 11 metres undoubtedly works over great distances, but also that this wave was mostly the best for day communication to South America: it was even heard sometimes when part of the path was in darkness. Maximum intensity was received at Buenos Ayres when the angle of radiation at the transmitter was

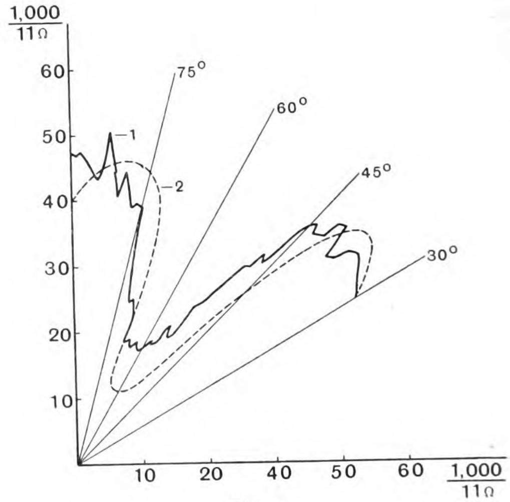


Fig. 7.

38 degrees and a second somewhat smaller maximum with an angle of 80 degrees. The figure below shows the average values of the intensity received for different angles of the reflector.

It took two men less than four minutes to move the reflector so that the angle of radiation turned through from 30 degrees to 90 degrees. In about 10 per cent. of the observations no maximum could be found when the reflector was rotated.

MEASUREMENTS AND STANDARDS.

"UNIVERSAL" FREQUENCY STANDARDISATION FROM A SINGLE FREQUENCY STANDARD.—J. K. Clapp. (*J. Opt. Soc. Amer. and Rev. Sci. Instr.*, 15, 1, pp. 25-47.)

Description of a method for obtaining from a single frequency standard source (quartz plate oscillator) a very large series of frequencies related to the known frequency by a ratio of simple integers. The frequencies thus attainable range from a few hundred to several millions of cycles per second, covering the entire gamut of audio and radio frequencies now in use. In addition to providing a means for the calibration of oscillators and wavemeters and of obtaining a desired frequency for laboratory measurements, the method can also be used to effect a direct comparison of frequency standards.

CONFRONTI FRA MISUSE DI FREQUENZA, PER MEZZO DI PIEZORISUONATORI (Comparison between measurements of frequency by means of piezo-resonators).—G. Vallauri. (*L'Elettrotecnica*, 14, 27, pp. 682-684.)

DISCUSSION AT PITTSFIELD MEETING. (*Journal A.I.E.E.*, September, 1927, pp. 955-967.)

Report of the discussions at the regional meeting in Pittsfield, Mass., last May, which include discussion of several of the papers dealing with measurements at high frequencies prepared by the Committee on Instruments and Measurements during the year 1926-1927. The discussion at Pittsfield on "Notes on the Use of a Radio-Frequency Voltmeter" is given in the October number, p. 1115.

HIGH-FREQUENCY MEASUREMENTS.—A Knowlton. (*Journ. Amer. I.E.E.*, October, 1927, pp. 1033-1040.)

Report of the Committee on Instruments and Measurements with a long bibliography.

The report is discussed on page 1127 of this same issue.

THE ALTERNATING CURRENT BRIDGE AS A HARMONIC ANALYSER.—I. Wolff. (*J. Opt. Soc. Amer. and Rev. Sci. Instr.*, 15, 3, pp. 163-170.)

SUBSIDIARY APPARATUS.

A HOT WIRE VACUUM GAUGE.—A. M. Skellett. (*J. Opt. Soc. Amer. and Rev. Sci. Instr.*, 15, 1, pp. 56-58.)

Description of a new gauge with which pressures as low as 6 by 10^{-6} mm. have been accurately measured.

THE TORUSOLENOID.—R. Gunn. (*Proc. Inst. Radio Engineers*, 15, 9, September, 1927, pp. 797-808.)

Description of an improved high frequency inductance of radical design, representing the successful attempt to combine into one inductance all the desirable features of both the toroid and the single layer solenoid. The new inductance has been found to incorporate the following features: substantially zero external magnetic field; a high value for the "gain" (a measure of coil performance); very low distributed capacity; and no major disadvantages.

GLEICHSTROM - HOCHSPANNUNGSMASCHINEN ALS ANODENGENERATOREN (Direct current high tension machines for supplying the anodes of valve transmitters.)—E. Rappel. (*E.T.Z.*, 48, 36, pp. 1285-1290.)

Discussion of the construction and action of the machines, also of the causes of the harmonics in the direct tension together with means of eliminating them.

DAS SCHALTEN GROSSER LEISTUNGEN MIT QUECKSILBERDAMPFRÖHREN IN DER DRAHTLOSEN TELEGRAPHIE (The control of large outputs in wireless telegraphy with mercury vapour tubes).—H. Schuchmann. (*Elekt. Nachr. Technik*, 4, 9, pp. 396-399.)

Description of an arrangement for controlling direct current and alternating current of any frequency by means of the mercury vapour switch. Oscillograms are shown.

ÉTUDE ÉLECTRIQUE DE QUELQUES REDRESSEURS (Electrical investigation of some rectifiers). —J. Quinet. (*Radio Revue*, October, 1927, pp. 455-463.)

A study of the working and properties of some rectifiers with a view to supplying receivers directly from the mains or charging accumulators.

AUTOMATIC WIRELESS ALARM DEVICE. (*Journ. Sci. Instr.*, 4, 12, p. 395.)

Brief account of a new automatic alarm device for giving warning on a vessel where constant watch cannot be kept, which is described in a leaflet No. 2051 recently issued by Messrs. Siemens Brothers & Co., Ltd.

EIN NEUE BAUART DES KATHODENOSZILLOGRAPHEN (A new method of constructing cathode oscillographs).—W. Rogowski, E. Flegler and R. Tamm. (*Archiv. für Elektrot.*, 18, 6, pp. 513-524.)

ÜBER DIE WIRKUNGSWEISE DER KONZENTRIERUNGSSPULE BEI DER BRAUNSCHEN RÖHRE (On the manner of working of the concentrating coil in the Braun tube).—H. Busch. (*Archiv. für Elektrot.*, 18, 6, pp. 583-594.)

MIKROPHONE FÜR HOCHWERTIGE ÜBERTRAGUNG (Microphones for high quality transmission). —C. A. Hartmann. (*Elekt. Nachr. Technik.*, 4, 9, pp. 375-378.)

After first explaining how the frequency amplitude relation for microphones is obtained, the extent to which it has been able to reduce distortion in the case of some representative types is shown. Consideration is made of high quality carbon microphones, and Gerlach's band microphone in the class of electrodynamic microphones, also of the condenser microphone for high quality transmission developed in America and Germany. Frequency and amplitude curves are shown and compared with those of an ordinary carbon microphone.

ELECTROMAGNETIC MICROPHONE.—I. Koga. (*Journ. Inst. Elect. Eng. Japan*, No. 470, pp. 906-909.)

The high-frequency oscillatory current of a valve is varied both in frequency and intensity, under certain conditions, when changes occur in (1) the magnetic or static coupling between plate and grid circuit, and (2) the magnetic coupling between the oscillatory circuit and a short-circuited coil or a metallic diaphragm placed nearby. If such a coil or metallic diaphragm is made to vibrate by a sound wave, the system may be employed as a microphone transmitter, the output of which is stated to be considerably greater than the Marconi electromagnetic microphone and others, also in the case of a metallic diaphragm, the construction of the microphone is much simpler than the present condenser type of microphone transmitter.

NEUES ÜBER RUNDFUNKAUFNAHMEN (New information on broadcast "pick-up" devices). —W. Schäffer. (*Elekt. Nach. Technik.*, 4, 9, pp. 387-390.)

In practice it is found that reception quality is prejudiced much less by inferior reproduction of the

highest and lowest frequencies than by the introduction of harmonics that are not present in the original—due to faulty working of the contrivances. Methods of discovering this latter form of distortion are discussed here, also the elimination is investigated of sources of error arising from the acoustical conditions in the microphone cavities.

MOTIONAL IMPEDANCE TEST OF LOUD-SPEAKERS.—K. Kurokawa and T. Hirota. (*Journ. Inst. Elect. Eng. Japan*, No. 469, August, 1927, pp. 865-873.)

The results are given of analysing fourteen loud-speakers from prominent makers by the motional impedance method. (This paper is in English.)

STATIONS : DESIGN AND OPERATION.

DIE HAUPTFUNKSTELLE NORDDEICH (The Norddeich high-power station).—W. Meyer. (*Telefunken-Zeitung*, 45/46, pp. 102-107.)

Description of the German Post Office coastal wireless station at Norddeich, whose equipment until recently comprised two 5kW valve transmitters and various others of smaller output, but which now includes two large Telefunken valve transmitters of 20 and 10kW respectively. Reconstruction of the antenna system will be carried out in the near future. New station buildings have been erected, views of which are shown.

AMERICA'S NEW 100KW TRANSMITTER.—A. Dinsdale. (*Wireless World*, 5th October, 1927, pp. 491-494.)

Illustrated description of this new Schenectady broadcast transmitter, which uses two 100kW valves in the high-power amplifier unit and three more in the modulator unit, and a preliminary report of the results of thirty days' special test.

NEW AMERICAN 50KW BROADCAST TRANSMITTER. (*Wireless World*, 19th October, 1927, pp. 550-554.)

Description of the plant at WEAF, Bellmore, Long Island.

BELGIUM—NEW STATION AT RUYSSELEDE. (*Electrical Review*, 14th October, 1927, p. 632.)

On 3rd October the Ruysselede wireless station, which has been designed specially for communication with America and the Congo, was inaugurated The new station lies between Ghent and Bruges and covers an area of 358 acres ; the aerials are slung between eight pylons, each 930 ft. in height, and both long and short waves will be used at will.

DIE ENTWICKLUNG DES EUROPÄISCHEN FUNKVERKEHRS (Development of wireless communication in Europe. — H. Lengsfeld. (*Telefunken-Zeitung*, 8, 45/46, pp. 99-102.)

Data are tabulated of the transmissions between Berlin and the principal capitals of Europe.

UNITED STATES RADIO. (*Electrical Review*, 28th October, 1927, p. 733.)

The leading chain of stations in America is that of the National Broadcasting Co. ; a rival chain was recently framed by the Columbia Gramophone Co., and it is now announced that a third chain of 60 stations is being formed. On 24th September last, the number of stations in the U.S.A. was 278, made up as follows : 170 of 0.5kW, 9 of 0.75kW, 44 of 1.0kW, 8 of 1.5kW, 7 of 2kW, 6 of 2.5kW, 2 of 3.5kW, 26 of 5kW, 2 of 15kW, 1 of 30kW and 3 of 50kW ; now there is one station using 100kW.

GENERAL PHYSICAL ARTICLES.

UNDAMPED EXTRA-SHORT WAVES OBTAINED WITH THE MAGNETRON.—K. Okabe. (*Journ. Inst. Elect. Eng. Japan*, No. 469, pp. 860-864.)

These very short waves were obtained with various valves where a high voltage was applied to the anode and the intensity of the magnetic field applied parallel to the cathode was increased above a certain value. The experiments showed that the following conditions require to be satisfied :—

1. The anode must be cylindrical in shape with its length greater than its diameter.

2. The intensity of the magnetic field must be kept in the vicinity of or above the critical value.

3. The diameter of the cathode must be sufficiently large.

4. The anode current must be properly adjusted, since for a given voltage and magnetic field there is an optimum value for the anode current.

UNTERSUCHUNG ÜBER DIE HAUTWIRKUNG IN EISENLEITERN (Investigation on the skin effect in iron conductors).—K. Mittelstrass. (*Archiv. für Elektrot.*, 18, 6, pp. 595-615.)

SUR LE CALCUL DE LA CHALEUR DÉGAGÉE PAR LES COURANTS DE HAUTE FRÉQUENCE (Calculation of the heat liberated by high frequency currents).—C. Fabry. (*Comptes Rendus*, 185, 15, 10th October, 1927, pp. 684-687.)

A short calculation showing that the Joule effect suffices to account for all the heat liberated, if note is taken of the fact that the current measured by the ammeter is the superposition of a conduction current and a capacity current, and that the former only liberates heat, the latter being wattless. The possibility of a liberation of heat due to dielectric hysteresis is not excluded. The subject is of interest for the difficult investigation of the dielectric constants of imperfect insulators.

ELECTROPHYSICS.—V. Karapetoff. (*Journ. Amer. I.E.E.*, October, 1927, pp. 1029-1031.)

Annual report of the Electrophysics Committee presented at the summer convention of the A.I.E.E., Detroit, Mich., June, 1927.

THE ELECTRICAL RESISTIVITY OF INSULATING MATERIALS.—H. Curtis. (*Journ. A.I.E.E.*, October, 1927, pp. 1095-1103.)

The belief is expressed that all the known facts concerning conductions through insulators can be explained by the ionic theory. While details of this theory are sufficiently developed to account for all the experimental facts in the case of gases, a complete explanation of the phenomena for liquids and solids awaits further investigation.

MAXWELL'S THEORY OF LAYER DIELECTRIC. (*Journ. Amer. Inst. E.E.*, October, 1927, p. 1006.)

A letter from E. R. Leghait referring to the discussion of Dr. Murnaghan's paper on Maxwell's theory of the layer dielectric, published in the July number of the *Journal A.I.E.E.*, p. 727.

SECONDARY EMISSION FROM MO DUE TO BOMBARDMENT BY HIGH-SPEED POSITIVE IONS OF THE ALKALI METALS.—W. J. Jackson. (*Physical Review*, 30, 4, pp. 473-478.)

THE VELOCITY AND NUMBER OF THE PHOTO-ELECTRONS EJECTED BY X-RAYS AS A FUNCTION OF THE ANGLE OF EMISSION.—E. C. Watson. (*Physical Review*, 30, 4, pp. 479-487.)

ELECTRIC STRENGTH OF SOLID AND LIQUID DIELECTRICS (abridged).—W. Del Mar, W. Davidson and R. Marvin. (*Journ. Amer. Inst. E.E.*, October, 1927, pp. 1002-1006.)

Abstract of a report to the Division of Electrical Engineering of the National Research Council. The report is a summary of existing literature and it is hoped that its discussion by the Institute will bring out obscure phenomena and new interpretations of the data reviewed and that it will afford a starting point for original research in many directions.

The report is discussed on page 1127 of this same issue.

OVER DE ONDULATIETHEORIE VAN EEN DEELTIGE, ZIJN UITGESTREKTHEID EN ZIJN BESTENDIGHEID (On the wave theory of a particle, its extent and permanence).—A. Fokker. (*Physica*, 7, 7, 1927, pp. 233-244.)

MISCELLANEOUS.

DER EMPFANG BILDTELEGRAPHISCHER SENDUNGEN (The reception of picture telegraphy).—Dr. Illberg. (*Telefunken-Zeitung*, 45/46, pp. 43-49.)

Some account of the methods employed in the reception of pictures telegraphed between Nauen and Rome and Rio de Janeiro, and the progress made on the reception side during these transmissions.

A RADIO INTER-COMMUNICATING SYSTEM FOR RAILROAD TRAIN SERVICE.—H. C. Forbes. (*Proc. Inst. Radio Engineers*, 15, 10, October, 1927, pp. 869-878.)

The problem of communication between the front and rear ends of long freight trains is briefly discussed and a two-way telephonic radio intercommunicating system, developed for this service, described. The results of tests of the apparatus under working conditions are also given.

A COMBINED RADIO GRAMOPHONE INSTALLATION.—A. Dinsdale. (*Wireless World*, 19th October 1927, pp. 539-542.)

Description of an electrostatic pick-up energised with H.F. oscillations from a broadcast receiver.

ELECTRICAL REPRODUCTIONS FROM PHONOGRAPH RECORDS.—E. W. Kellogg. (*Journ. A.I.E.E.*, October, 1927, pp. 1041-1049.)

Electrical reproduction may be considered in three steps, (1) generations of a voltage by the vibrations of the needle, (2) amplification, (3) conversion of electrical power into sound. The first of these steps involves some interesting mechanical and electrical problems, and it is with these that the paper primarily deals. Several types of phonograph "pick up" are possible; electrostatic, piezo-electric, electromagnetic, and variable resistance or microphonic: in the device considered here the electromagnetic principle is employed.

D.E.H.

ERRATUM.

"RESONANCE IN SERIES AND PARALLEL CIRCUITS."—Equation 5 on page 677 is correct but in the line below $C = \frac{1}{\omega^2 C^2 + R^2}$ is given instead of $C = \frac{L}{\omega^2 L^2 + R^2}$

Esperanto Section.

Abstracts of the Technical Articles in our last Issue.

Esperanto-Sekcio.

Resumoj de la Teknikaj Artikoloj en nia lasta Numero.

PROPRECOJ DE CIRKVITOJ.

RESONANCO ĈE SERIAJ KAJ PARALELAJ CIRKVITOJ. —H. J. Boyland.

La artikolo analizas certajn kombinojn de Induktanco, Kapacito, kaj Rezisteco, por derivi la parencecon, kiu devas ekzisti por kontentigi la kondiĉojn :—

Por Seriaj Cirkvitoj :—

(*a*) Maksimuma potenciala diferenco trans la induktanco ;
(*b*) Maksimuma p.d. trans la kapacito ;
(*c*) La kurento devas esti maksimumo.

Por Paralelaj Cirkvitoj :—

(*d*) La ekvivalenta reaktanco devas esti nulo ;
(*e*) La impedanco devas esti maksimumo.

Simpla matematika analizo estas donita por la diversaj ekzemploj de

Seriaj Cirkvitoj :—

1. Induktanco kaj kapacito en serio sen rezisteco ;
2. Induktanco, kapacito kaj rezisteco en serio ;
3. Induktanco kun enhavita rezisteco en serio kun kapacito.

Paralelaj Cirkvitoj—

4. Pura induktanco (sen rezisteco) kaj pura kapacito en paralelo ;
5. Induktanco kaj rezisteco en paralelo kun pura kapacito ;
6. Induktanco kaj rezisteco en paralelo kun kapacito kaj rezisteco.

Esprimoj estas derivitaj por la diversaj ekzemploj montritaj.

LA FUNKCIADO DE VALVOJ EN PARALELO.—R. P. G. Denman.

La artikolo provizas ekzamenon pri la ĝenerala ekzemplo de nombro de valvoj funkciantaj paralele, portantaj komunan ŝarĝon. La ekzemplo de *n* baterioj en paralelo estas nune ĝeneraligita laŭ la Leĝoj de Kirchhoff, kaj la esprimoj derivitaj estas aplikitaj al tiu de *n* valvoj en paralelo. Speciala ekzemplo estas donita pri du valvoj de konataj malsimilaj karakterizoj (t.e., de malsama modelo), kun plua ekzemplo de du valvoj de simila modelo sed kun μ kaj r malsamaj je ĉirkaŭ 10%. Oni utiligas la kurvojn Anodvoltajn—Anodkurentajn (vidu E. Green, *E.W. & W.E.*, Julio-Aŭgusto, 1926a), kaj oni montras ke, je certaj okazoj, la malplibona valvo regas la situacion, kaj ke la alia, kvankam eventuale kapabla trakti pligrandan potencon, ne povas ricevi ĉi tion sen troŝarĝo de la malsupera valvo. La utiligo de apartaj krad-potencialaj alĝustigoj permesus plibonan elmeton. Oni uzas similan rezonadon rilate al la utiligo de du aliaj valvoj samspecaj, sed kun iomete malsimilaj karakterizoj.

La aŭtoro finas, rimarkigante, ke eble fabrikistoj solvus la malfacilecon se ili provizus malgrandajn grupojn de potencaj valvoj kun karakterizoj garantiitaj laŭ apudaj limoj.

RICEVADO.

KELKAJ NOTOJ PRI L'EFEKTO DE KUPLO INTER KADRAJ KAJ BAT-OSCILATORAJ CIRKVITOJ EN SUPERHETERODINA RICEVILO.—E. H. Ullrich and A. H. Reeves.

Oni unue aludas al la fakto, ke en supersona ricevilo la kuplo inter la batanta oscilatoro kaj la ricevila kadro igas, ke la agordo de iu cirkvito influas la alian. Sub 100 metroj ĉi tio fariĝas ĝenema. Mallonga matematika analizo de ĉi tiuj efektoj estas donita, kaj metodo enkonduki la batantan oscilatoran tension estas diskutita kaj ilustrita. Je 200 metroj neniu variado estis detektita. Je 50 metroj la anodkrada kapacito havis percepeblan perturbigan efekton sed estis korektebla per ekvilibriga kondensatoro.

TEORIO PRI RICEVAJ ANTENOJ.—F. M. Colebrook.

La artikolo estas verkita kun la intenco provizi respondojn al la demandoj :—

1. Kia estas la efektiva impedanco de riceva anteno laŭ la vidpunkto de interrilatigita aparato ?
2. Ĉu la efektiva impedanco dependas de (*a*) la speco de la agorda cirkvito, (*b*) la distribuo de la kampo kaŭze de la signalo ?
3. Kiun rolon ludas la distribuita rezisteco de anteno ?
4. Kiom estas la efektiva alteco de anteno, kaj ĉu ĝi dependas de (*a*) la agord-cirkvitaj kondiĉoj, (*b*) la kampa distribuo ?
5. Ĉu estas optimuma distribuo por difinita longeco de anteno ?

La ĝenerala temo de la riceva anteno estas analizita matematike kaj aplikita al la solvo de ĉi tiuj punktoj.

La respondoj deduktitaj el ĉi tiuj demandoj povas esti mallonge resumitaj laŭjene :—

1. La anteno povas esti rigardita kiel ordinara impedanco de la tipo $(R+jX)$ en serio kun efektiva Elektromova Forto kaŭze de la signalo ;
2. La efektiva impedanco dependas nur de la elektraj konstantoj kaj la formo de la anteno ;
3. La distribuita rezisteco de la anteno eniras en la rezistecan komponanton de l'efektiva impedanco kaj ankaŭ, kvankam ne multege, en la efektivan reaktancon ;
4. La efektiva alteco ne estas influita per la agordigo de la anteno, sed dependas de la frekvenco kaj kampa distribuo ;

5. Neniu ĝenerala respondo estas donebla pro tio, ke la efektiva alteco, kaj tial la efektiveco, de l'anteno dependas de la formo de la kampo en kio ĝi troviĝas.

VALVOJ KAJ TERMIONIKO.

X-RADIOJ KAJ RADIO-VALVOJ.—D-ro. J. Taylor.

Post mallonga diskutado pri la proprecoj de X-radioj, la aŭtoro priskribas la generadon de ĉi tiu radiado, per malalttensia tubo kun "Coolidge" (t.e., varmigita) katodo. Li tiam diras ke, principe, ĉiu senfadena diodo aŭ triodo estas generilo de X-radiado, kvankam la kvanto generita estas eble tre malgranda.

Oni priskribas eksperimentojn per tubo de proksimume valvelektroda konstruo, kun aldonitaj elektrodoj por la detekto, kaj mezuro de la X-radiado per fotoelektra rimedo. La eksperimentoj montras, ke devas esti produkto de mola X-radiado inter la triodaj kaj diodaj valvoj uzitaj en praktiko, speciale ĉe molaj valvoj.

DIVERSAĴOJ.

LA NACIA RADIO-EKSPOZICIO, OLYMPIA, 1927a.

Redakcia artikolo traktanta pri certaj el la montraĵoj ĉe la Brita Nacia Radio-Ekspozicio, tenita ĉe Olympia, Londono, de la 24a Sept. ĝis la Oktobro.

RESUMOJ KAJ ALUDOJ.

Kompilita de la *Radio Research Board* (Radio-Esplorada Komitato), kaj publikigita laŭ aranĝo kun la Brita Registara Fako de Scienca kaj Industria Esplorado.

MATEMATIKO POR SENFADENAJ AMATOROJ.—F. M. Colebrook.

Daŭrigita el antaŭaj numeroj. La nuna parto (Parto IV de la serio) traktas pri la aplikadoj de la antaŭa teksto al elektraj problemoj sub la fakaj rubrikoj de la Fundamentaj Leĝoj de Kurentaj Retaĵoj, Induktanco, Kapacito, Vektora Reprezentado de Retro-E.M.F.—oj, Vektora Analizo de Alternkurentaj Cirkvitoj, k.t.p.

Review of Publications.

QUARTZ.—PRESENT-DAY APPLICATIONS OF THE PIEZO-ELECTRIC EFFECT IN RADIO ENGINEERING. By A. Hinderlich, M.A. Published by Quartz Oscillators Ltd., 1, Lechmere Road, London, N.W.2. 67 pp. and 12 Figs. Price 2s. 6d.

Readers of *E.W.* & *W.E.* are familiar with the author's non-mathematical experimental style of approach to the quartz oscillator. No attempt is made to explain the theory or principles involved but a great number of practical wrinkles are given in the technique of making and using quartz plates. The book is addressed to the wireless amateur who wishes to build a crystal-controlled oscillator unit, and it should answer this purpose admirably. There are sections on wavelength standards and miscellaneous applications, and an excellent bibliography giving references to sixty papers on the subject. There is also a list of patents which have been taken out for various applications of the quartz oscillator.

We make an effort to keep up with the slang with which the amateur loves to decorate the subject, but a "hay-wire" version of the quartz-controlled oscillator unit, is new to us; it is probably not unconnected with the fact that the book concludes with a section headed "Americana."

LOW FREQUENCY AMPLIFICATION. A pamphlet of 48 pages issued by the R.I. and Varley Co. Price 1s.

The transformer lion has laid down beside the resistance-capacity lamb and this pamphlet represents their joint effort; the first half is mainly devoted to the lion and the second half to the lamb. Who would have expected to read in a pamphlet bearing the letters "R.I." that "the overwhelming advantages of resistance-capacity coupling for low frequency amplifiers are now so well-known and acknowledged that it must soon absolutely supersede any other form of coupling where faithful, pure, and realistic reproduction of speech and music are desired? Seriously, however, we welcome this pamphlet which discusses the theory of both methods and gives National Physical Laboratory curves of amplification over the frequency range obtained by both methods using, of course, components supplied by the company. The transformer employed was the new R.I. super transformer which contains about 2½ times as much iron as their older model; they have probably found that the heavy direct anode current passing through the primary greatly reduces the effective inductance to the audio-current and necessitates this increase of iron. The transformer has three windings, the turns being in the ratio of 100 : 175 : 175; these can be connected in various ways to give different ratios depending on the A.C. resistance of the preceding valve. A warning is given that the anode current should not exceed 4 milliamperes through the first or 3 milliamperes through the other two windings.

A new method of coupling is recommended for use after high-amplification high-resistance valves; this consists in taking a connection from the anode of the valves through a 0.01μF condenser to the grid of the following valve, in addition to the ordinary transformer arrangement. It appears to be a combination of transformer and choke coupling and is referred to in the pamphlet as balanced inductive coupling; the reason for this name is not clear as no explanation is given of the principles underlying the suggested arrangement.

G.W.O.H.

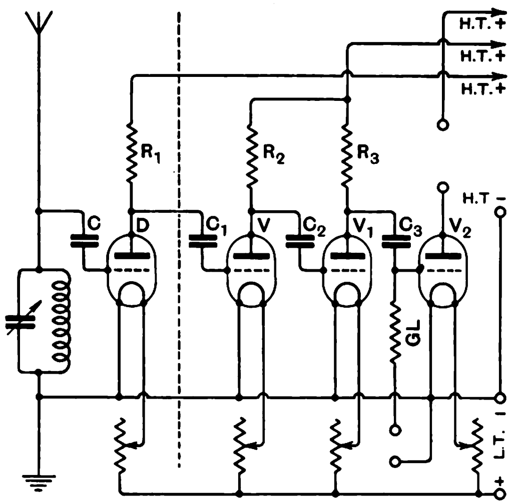
Some Recent Patents.

The following abstracts are prepared, with the permission of the Controller of H.M. Stationery Office, from Specifications obtainable at the Patent Office, 25, Southampton Buildings, London, W.C.2, price 1/- each

RESISTANCE-CAPACITY COUPLINGS.

(*Application date, 7th July,* 1926. *No.* 276,479.)

Plate resistances R_1 R_3 of the order of megohms, 2 megohms being mentioned as a suitable value, are used in combination with insulated or "free" grids. As shown in the Figure, a detector stage D is coupled to three stages V, V_1, V_2, of low



frequency amplification through resistances R_1 R_3 and coupling condensers C_1 C_3 having a capacity not less than 0.0003μF. A high tension voltage of 60 is used on the first three valves, and 100 on the last stage.

The elimination of grid-leaks and biasing batteries removes a source of damping on the input circuit, and leads to improved selectivity. In the case of the last valve V_2, a high leak of from 5 to 10 megohms may be provided to relieve the heavy load. There is a tendency for the grid of the first valve to acquire an unduly large negative bias when the filaments are first lit. In order to prevent any temporary paralysis due to this cause, the rheostat switch may momentarily connect that grid to the filament circuit at the instant of switching on; or a separate switch may be provided for this purpose.

Patent issued to P. L. Wostear and R. H. Billingsley.

DUAL-DIELECTRIC CONDENSERS.

(*Application date, 5th October,* 1926. *No.* 276,508.)

A movable plate of solid dielectric, such as resin, is arranged to interleave certain of the plates of a tuning condenser, the remainder of the plates being separated by air dielectric as usual. One knob may control the position of the solid dielectric, whilst another controls the air-separated plates; or there may be a simultaneous control for both parts of the condenser. The instrument is particularly suitable for combined long and short-wave receivers, as the capacity can be varied practically instantaneously, from, say, 0.0005 to 0.005μF.

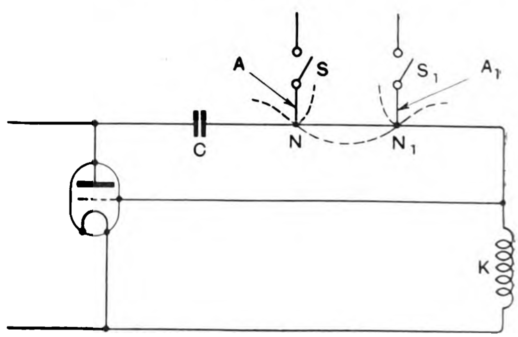
Patent issued to C. Hollins.

SHORT-WAVE RADIATION.

(*Convention date (Germany), 7th October,* 1925. *No.* 259579.)

In short-wave signalling the generator is usually connected to the radiating system either by inductive coupling or through a capacity. According to the present invention the aerial is connected directly to the oscillation generator by a metallic conductor located at a voltage node. As shown in the Figure, the main oscillatory circuit comprises a simple wire connection between the electrodes, together with a series capacity C.

The inductance of the wire, the condenser C, and the inherent grid-anode capacity of the valve are the factors which determine the frequency of the oscillations generated. Reaction is secured through a choke K and the inter-electrode capacity of the valve. Stationary waves are set up in the Lecher wire system so formed, and a number of radiating aerials A, A_1 are connected at the nodal points



N, N_1. Several aerials may be arranged in this way to form a directional system. Maximum radiation only takes place when the length of each aerial is equal to one or an odd number of quarter wavelengths. This fact is utilised to control signalling by inserting switches S, S_1 to alter the effective lengths of the antennæ.

Patent issued to Dr. A. Esau.

SHORT-WAVE TRANSMISSION.

(*Convention date* (*Germany*), *7th October*, 1925. *No.* 259577.)

In short-wave radiation emitted at an angle of from 45 to 70 degrees to the horizontal from an aerial insulated from the ground, it is found that an improved range can be secured when the conductivity of the earth in the vicinity of the transmitter is artificially increased. Further, it is found that maximum efficiency occurs when the area of the artificially-prepared soil bears a definite relation to the wavelength employed. The present invention consists in preparing the ground near the aerial over an area having a radius of from three to four times the signal wavelength, either by laying down wire star or similar networks; or by covering it with metal gauze, chips, or filings; or by impregnating it with salt or other chemical solutions.

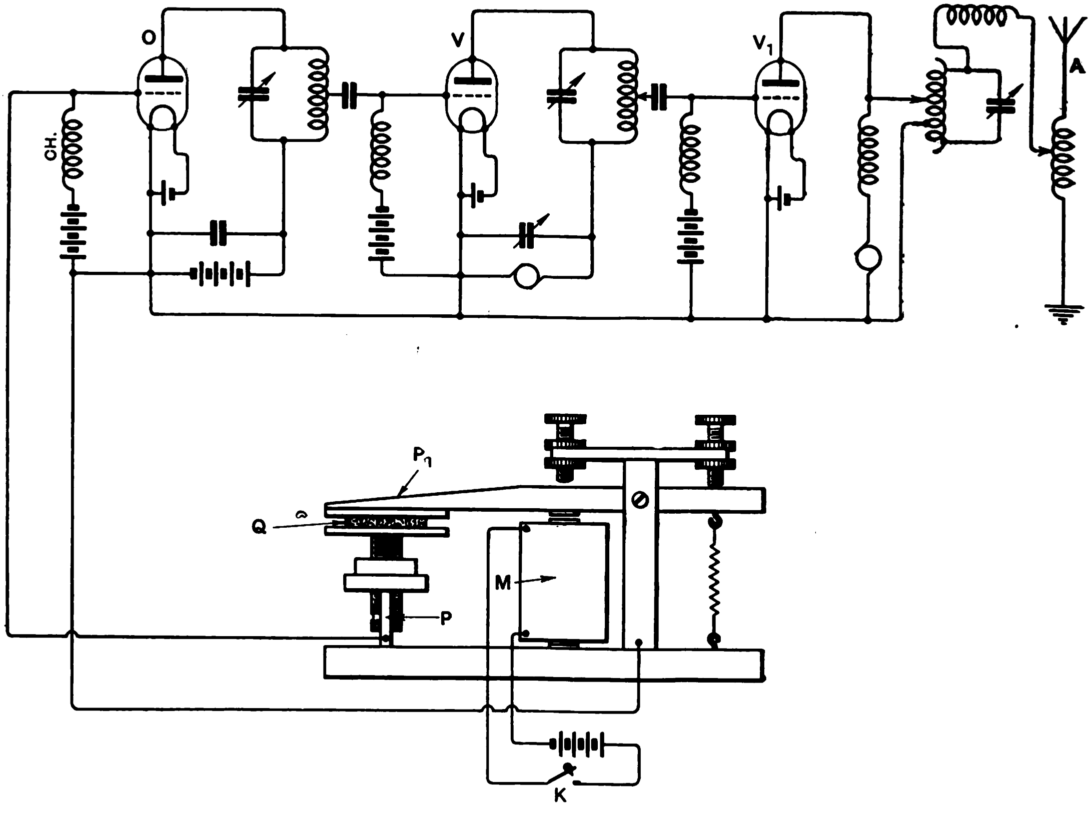
Patent issued to Dr. A. Esau.

SIGNALLING BY PIEZO-CRYSTAL CONTROL.

(*Convention date* (*U.S.A.*), *7th August*, 1926. *No.* 275581.)

Signalling is effected by varying the space relationship of two plates separated by a piezo-electric crystal. The crystal Q is in the grid circuit of a low-powered oscillator O, and is shunted by a radio-frequency choke Ch in series with a grid-biasing battery. It is also mounted between a rigid support P and a plate P_1, or armature, acted upon by an electro-magnet M included in a circuit containing the signalling key K.

When the plate P_1 is moved towards or away from the crystal the capacity value of the latter is altered. As the crystal forms a part of the condenser dielectric, the intensity of the transverse electric field changes accordingly, together with the frequency output from the oscillator O. The latter is coupled through successive amplifying stages V, V_1 to the aerial A.



A very small movement of the plate P_1 is sufficient to cause a frequency shift of from 500 to 1,000 cycles, which is ample to impress signal variations on the radiated energy. Such a keying device consumes no appreciable power, and has the additional advantage that it is safe in use, since no voltage is involved higher than that necessary to secure a proper bias on the grid of the oscillator tube O.

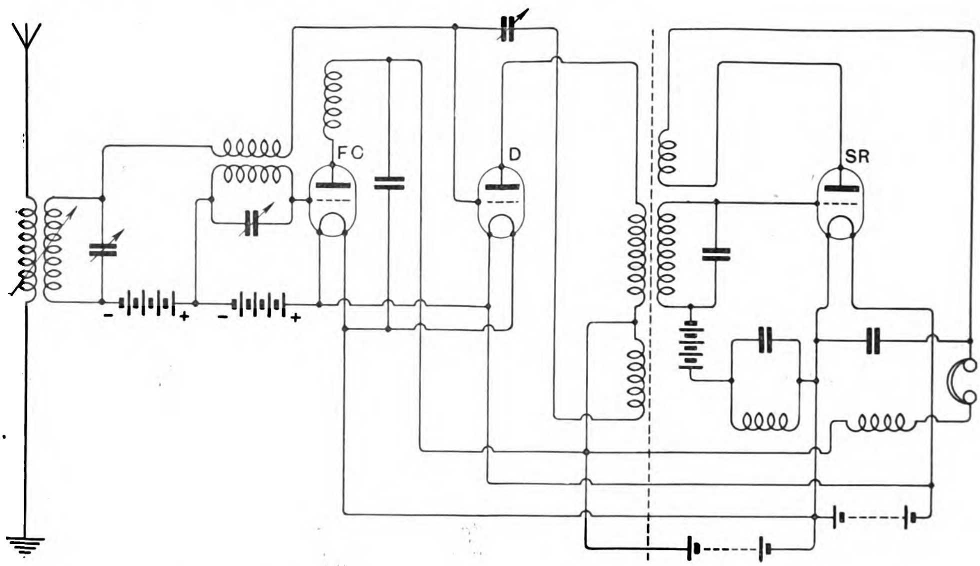
Patent issued to the Westinghouse Electric Co.

SUPER-REGENERATO. ONTROL.

(*Convention date* (*U.S.A.*), *12th April*, 1926. *No.* 269207.)

In order to simplify the control of a super-regenerative receiver, the circuits SR are tuned permanently to a definite optimum value, and the

incoming signals are then heterodyned by a frequency-changer *FC*, until the ensuing beat frequency coincides with that to which the super-regenerator has been set. The beat frequency is preferably of the order of 3,000 kilocycles, the incoming signals being stepped up to this value by adjusting the circuits of *FC*. A detector valve *D* transfers the stepped-up frequencies to the permanently-tuned super-regenerative amplifier *SR*.

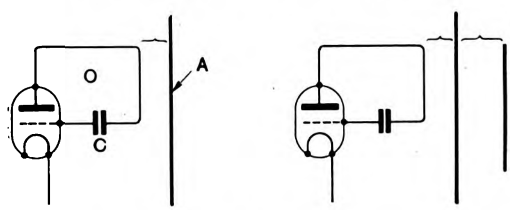


Patent issued to Metropolitan Vickers Co.

SHORT-WAVE GENERATORS.

(*Convention date* (*Germany*), *18th February*, 1926. (*No.* 266372.)

In attempting to generate very short waves, a natural limit is imposed by the electrical constants, and particularly the inter-electrode capacity of the valve oscillator. It is, however, known that it is possible, by coupling one oscillatory system to another, to produce a number of separate wavelengths dependent upon the degree of coupling employed. Advantage is taken of this fact to produce waves varying from a few metres down to a few centimetres in length.



In the Figure the constants of the main oscillatory circuit *O* comprise the plate-grid electrode capacity, an external capacity *C* and the connecting wires. This circuit is placed in close proximity to a radiating rod or aerial *A*. For a certain degree of coupling between the circuits, the radiated wave will correspond with the fundamental frequency of the circuit *O*. For a tighter coupling, two waves will appear, the frequency difference between them depending upon the closeness of coupling. This difference can be increased to the required degree by detuning the aerial *A* from the circuit *O*. Either frequency may be selected for transmission; or the two frequencies may be made approximately equal, and a common signal applied to both, with the object of minimising fading effects.

Patent issued to Dr. A. Esau.

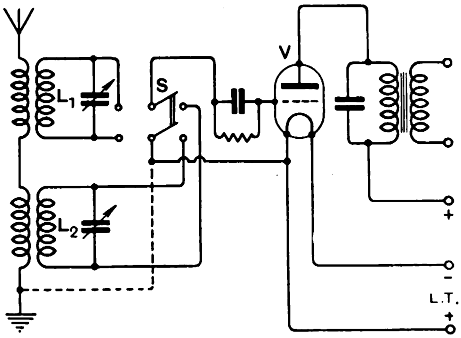
DUAL-RECEPTION RECEIVERS.

(*Application date*, *14th September*, 1926. *No.* 277799.)

Two or more differently-tuned units are associated with the aerial or input circuit of a receiver, and a switch is arranged so that when one unit is feeding desired signals to the detector the other unit is functioning as a wave-trap to eliminate interference. Various combinations of acceptor, rejector, and absorber circuits designed to ensure alternative reception from at least two transmitting stations, free from mutual interference, are described in the specification.

In the example shown in the Figure the unit L_1 is tuned, say, to station A, whilst unit L_2 is tuned to a different station B. With the switch *S* in the left-hand position, the unit L_1 is inserted across the grid and filament of the detector *V*. This brings in station A. Simultaneously, interference from station B is minimised by the open-circuited unit L_2 which acts as a wave-trap or "absorber" to signals of this frequency. When the switch is moved over to the right, the circuit connections of

the units L_1 and L_2 are reversed. Signals from station B are then received, any interference from station A being cut out by the unit L_1 which acts as a wave trap. The aerial inductances, which



are small relatively to those of the units L_1 and L_2, are so chosen that the total aerial impedance is suitable to receive either station A or B.

Patent issued to British Thomson-Houston Co. and T. H. Kinman.

A STABILISED HIGH-FREQUENCY CIRCUIT.

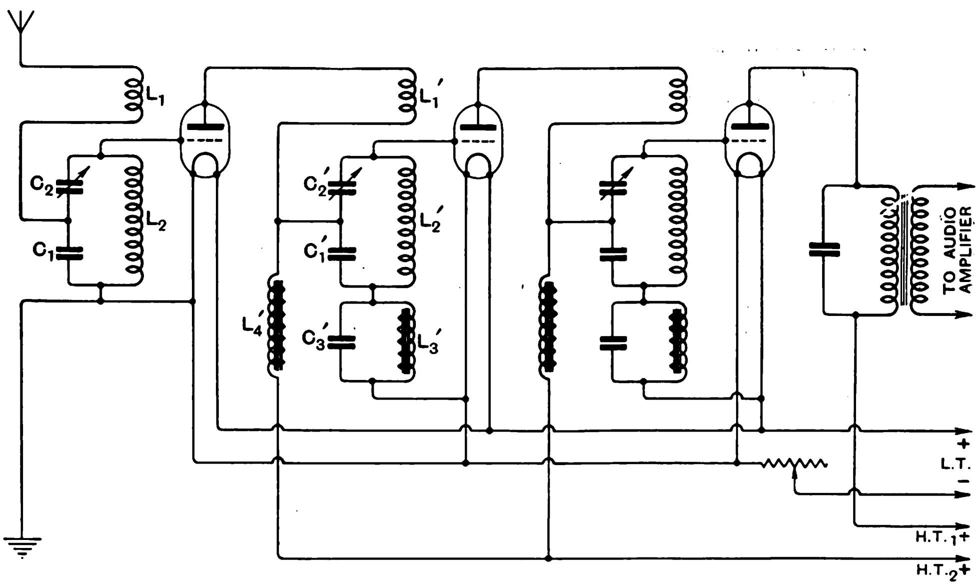
(*Convention date* (*U.S.A.*), *24th December*, 1925. *No.* 263804.)

The aerial circuit comprises an inductance L_1 and capacity C_1, and is coupled to a secondary circuit C_1, C_2, L_2, forming the input of the first valve, partly through the common condenser C_1, and partly by the coils L_1, L_2. By suitably adjusting the polarity or phase of the coils L_1, L_2, the effective transfer of energy through the combined couplings can be made a positive or negative factor, owing to the fact that the rate of energy transfer across the capacity coupling decreases as the working frequency increases, whilst the inductive transfer across the coils falls off, and *vice versa*.

In the plate circuit, the coils L_1' and L_2' and the coupling condensers C_1', C_2', and C_3' can be adjusted so that the overall reactance of the system may be either inductive or capacitative, or purely resistive in character. The precise theoretical conditions involved are set out at length in the specification.

The objects aimed at are to secure a complete elimination of the inter-electrode capacity effect throughout the entire tuning range of the receiver, whilst at the same time keeping the effective reactance of the coupling elements at a low value, so as to facilitate an efficient and constant energy-transfer ratio from one valve to the next. The arrangement is stated to be independent of the dimensions or spacing of the valve electrodes, so that any one particular type of valve may be replaced by another without upsetting the balance of the system. High-frequency chokes L_3' and L_2' are inserted across certain of the coupling condensers as shown, so as to permit the necessary operating voltages to be applied direct to the plate and grid of each valve from the high and low tension batteries.

Patent issued to E. H. Loftin.



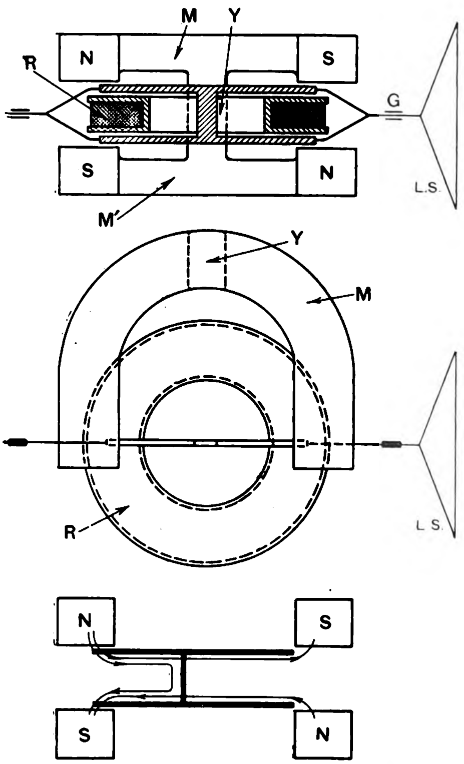
LOUD-SPEAKERS.

(*Application date*, *7th May*, 1926. *No.* 277052.)

A ferromagnetic armature is mounted so as to move longitudinally within a narrow air gap between permanent pole-pieces, so that the to-and-fro movement is unrestricted mechanically by the width of the gap. The energising coil is fixed, but is so mounted around the armature as to allow a free vibration of several millimetres. The arrangement is highly sensitive, a comparatively small current

producing a large lateral displacement of the armature. The arrangement of the parts is shown in plan and in elevation in the figure, whilst the distribution of magnetic flux at a particular instant of operation is also shown.

The permanent system comprises two magnets, M, M_1 connected by a central yoke Y, the polarity of adjacent faces being opposed as shown. Mounted



within the air-gap is a movable H-shaped armature, shown shaded, one end being connected by rods passing through a guide G to the cone diaphragm of a loud-speaker LS. The armature is energised by means of a ring-shaped winding R, which is immovably mounted between the upper and lower legs of the armature, and at such a distance from the centre leg as to allow the armature to vibrate freely in a lateral direction between the permanent poles, N, S.

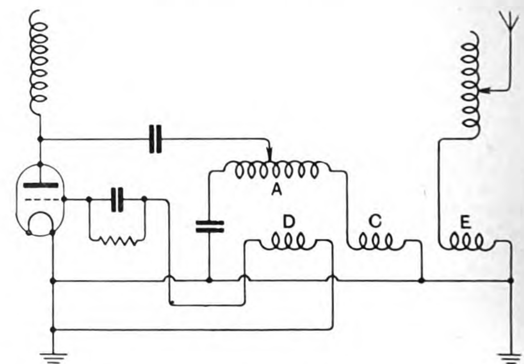
When there is no current flowing in the ring R, the magnetic flux through the system is such as to retain the armature in a definite position of equilibrium. The effect of the energising current is to vary the polarity of the armature, and so cause it to move alternatively to the right or left as the direction of current-flow reverses. At the moment shown in the bottom figure the resulting magnetic flux is pulling the armature towards the left.

Patent issued to H. Wade, the invention being a communication from the Philips Glowlamp Co. of Eindhoven.

TRANSMITTING CIRCUITS.

(*Convention date* (*Holland*), *22nd May*, 1926. *No.* 271450.)

In order to prevent the coupling effect known as "oscillation hysteresis," in which two separate wavelengths are produced and the system tends to swing over from one to the other, advantage is taken of the fact that the two wavelengths have a phase-difference of 180 degrees to make the reaction, say, on λ_1 greater than that on λ_2 and so eliminate the latter. According to the present invention the coupling coil C constitutes



only a small proportion of the total inductance A, C of the main oscillatory circuit, whilst the associated coil E is only a small part of the total aerial inductance, the third coil D constituting the grid inductance. The winding direction of the coil E is so chosen that for wave λ_1 the currents in coils C and E are in the same direction, whilst for wave λ_2 they are in opposition. As the coupling is increased the system therefore tends to become stabilised on the wavelength λ_1.

Patent issued to Nederlandsche Seintoestellen Fabrik.

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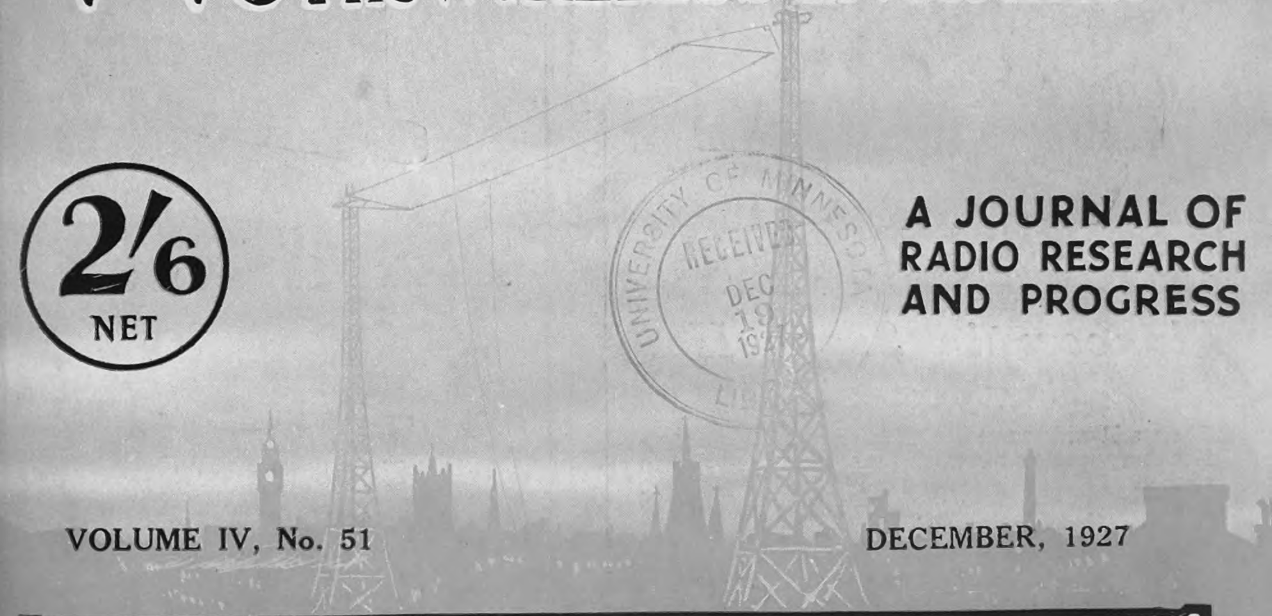

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A JOURNAL OF RADIO RESEARCH AND PROGRESS

VOLUME IV, No. 51 DECEMBER, 1927

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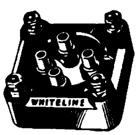

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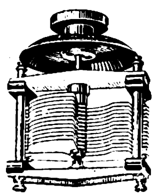

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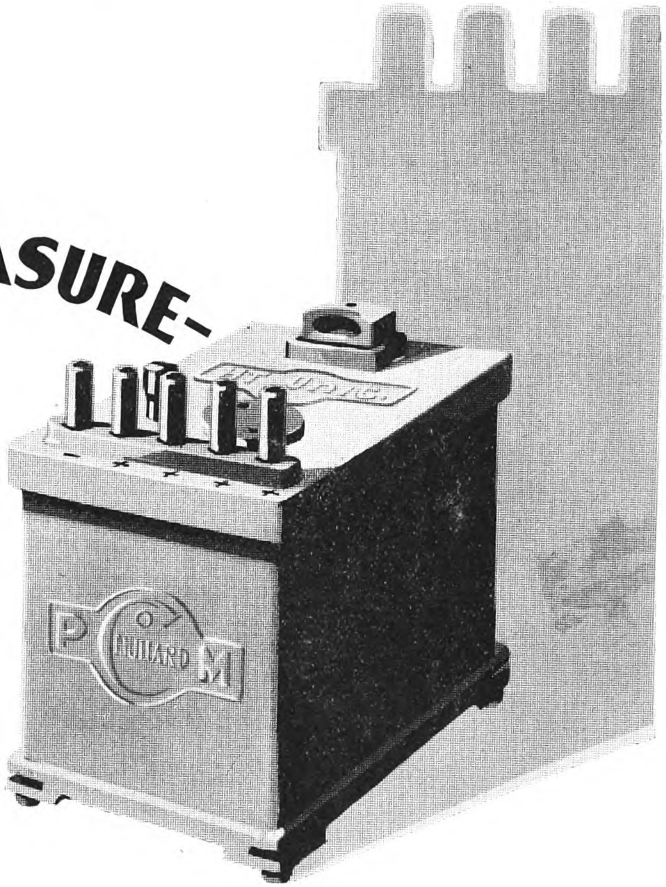

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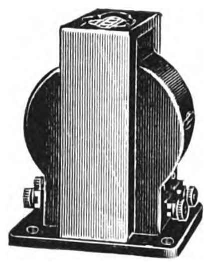

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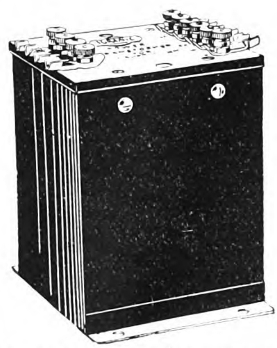

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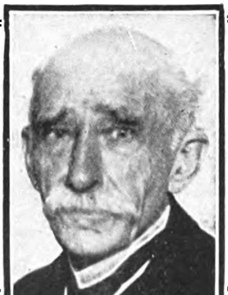

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